THE USE OF RADIOACTIVE GOLD-198 FOR THE TREATMENT OF MALIGNANCIES

W. M. McLELLON

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By
WALDRON MURRILL MCLELLON
BSc., BCE, MCE

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FOREWORD

The research reported in the paper was accomplished during the past year under the direction of Dr. William G. Myers of the Staff. It was a continuation of research on the application of radioactive gold wire to cancer therapy commenced by Lt. B. H. Colmery, U.S.N., in the preceding year. Since such a task is very broad in scope, complete coverage of such application is not given here. The main purpose of this research was to extend previous knowledge so that the combined experience and data assembled would allow clinical application of the radioactive gold. It is felt that this initial task has been accomplished, though of course much additional information must be assembled further to evaluate and apply the method.

The author has been attending the Ohio State University under the Radiological Defense Program of the United States Navy. Primarily, the emphasis of the course lay with physics, however, there has been considerable attention given to physiology and related subjects in the curriculum. Since the application of radioactive gold to cancer therapy includes many physical and biological problems, it was felt by the author that such research would be beneficial in rounding out the training. Part of the cost of this research was borne by the United States Navy.

The writer is indebted to Dr. William G. Myers who was continually helpful during the course of the research. Also, Mr. A. D. Imhof, Mr. J. A. Muhlenpoh and Mr. R. D. Thomas made helpful suggestions and assisted with the experimental animals.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

THE USE OF RADIOACTIVE GOLD-198 FOR THE TREATMENT OF MALIGNANCIES

I. INTRODUCTION

Since radioisotopes became abundant, considerable research has been accomplished in investigating those suitable for cancer therapy. Radioactive gold, $_{79}Au^{198}$, has been one isotope selected for experimentation and many applications have been reported to date, for example (1,2,3,4). However, all work accomplished prior to the present research was in the application of gold colloids. No references have been found in the literature on any application of solid gold in therapy. Since gold-198 emits beta particles and gamma rays, the primary effect with colloidal gold is given by the beta particles. In the application of radioactive gold wire to therapy, these beta particles are shielded out and the gamma rays are primarily involved in therapy. This shielding is accomplished by enclosing the radioactive wire in a non-radioactive gold tubing shield that essentially eliminates all beta particles from the radiation field. These linear sources are then clipped to the lengths desired and are similar to linear radon sources.

Colmery (5), initiated the investigation of the radioactive gold wire. During the course of his research, the characteristics of gold were determined, initial dosage caloulations made and experimentation commenced. In this paper the basic information will remain as previously

given (5). Only modifications will be quoted as appropriate. A search of recent literature has been made for later work by other investigators with no success. Apparently the investigations at this university constitute the initial work on the subject. The objective then is to assemble information and experience that will allow such linear gold sources to be applied in therapy.

II. PROBLEMS IN CANCER THERAPY USING INSTERSTITIAL SOURCES

Cancer therapy is a broad field involving several types of treatment depending upon the particular type of tumor encountered. For example, surgery may be employed where it is possible completely to eradicate the tumor by this method without danger to the patient. In radiation therapy, Roentgen rays may be employed, or point or linear sources such as radium, radon, or cobalt may be used. The use of radioactive gold wire falls in the latter class of linear sources. These are cut to length as required by the case in question and are used in a pattern to give a proper dosage over some selected volume. Thus, the radioactive gold wire is to be used interstitially in therapy.

This type of application poses quite a number of problems. For example, there are different varieties of cancer. These may or may not be radiosensitive. Only the ones which respond may be treated thusly. Among these possible ones, the sensitivity will vary so that it will be necessary to suit the dose to the case in question. In addition, different sizes and shapes of the tumor masses will exist, thus requiring some special treatment method to insure a uniform field. Also, some may be readily accessible, and others may be inaccessible so that the insertion of radioactive seeds in a proper pattern becomes

very difficult. The problem of radiation received by the therapist is also present since he will be in close proximity to the sources during the insertion. All of these biological factors enter as therapeutic problems which must be considered by the therapist. It is essential that the radiation sources be placed properly and to be of such a size and shape as to cause maximum damage to the tumor and minimum damage to the patient.

The biological problems are accompanied by physical problems also. For example, there is the problem of calibration of sources. Since these interstitial sources are placed in tissues, it is impossible to measure the dose given in situ. Therefore, it is necessary to rely on a computed dose or one measured in a tissue-equivalent phantom with the same arrangement. Thus, the calibration problem enters into the picture since a calculated dose is based on a certain source strength. Radium and radon sources have been in use for nearly a half century and have been well standardized. However, there is no such standard initially for investigation of a new isotope. It is necessary to use a meter which is energy independent in the calibration to insure a minimum error. Thus until an accurate calibration method is established, the dose of radiation supplied may be considerably in error. This calibration and dose problem was summarized by Paterson (11) as follows:

> "In conclusion, it must again be emphasized that the problem which we have been considering is only that of knowing accurately what dosage we are giving. This is a distinctly separate question from the consideration of what dosage should be given."

Along with the problems of calibration and calculation of dosage is one of uniformity of field. Since odd tumor shapes may be involved, and since the sources are finite, inhomogenous, and will have some variation in size due to errors in preparation, variations in field intensity will result. In all applications, the linear sources should be so positioned as to provide as uniform a radiation field as possible. Actually there will be high and low spots in the volume. It is necessary to use the low spots as a measure of the dose given since a tumor is destroyed only if all individual cells are killed. In general, certain seed patterns are used in therapy that have been established by calculation and experiment. These patterns have been well worked out for radium and radon and similar knowledge will be required for applications of gold-198. This, again, is a physical problem that must be overcome.

Several other points come to mind that must be considered. For example, since there are considerable biological variations, the method must be flexible enough to allow treatment of all possible cases. This may be done by varying the seed arrangements, or source strengths, or both. Also, templates or other devices will be required

for accurate positioning. Suitable remote handling devices, special meters and other tools must be used to avoid radiation damage to therapists. In the cases where constant source strengths are used, the sources must be removed at the end of the selected exposure time to avoid damage to the patient. Thus, there are many special problems inherent in all applications of radioisotopes. The primary object as stated previously is to know accurately the dose given and have it restricted as far as possible to the actual tumor volume.

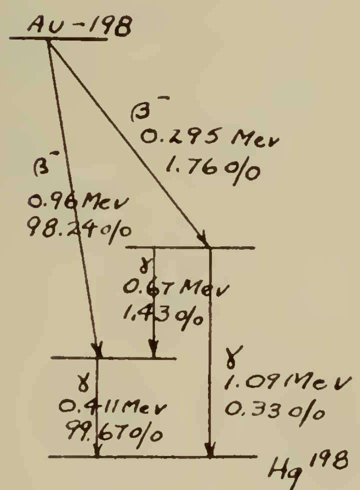
The application of radioactive gold wire interstitially will involve all of these problems. It will be necessary, therefore, by calculation and experiment to develop a proper technique and accumulate knowledge before it may be applied in therapy.

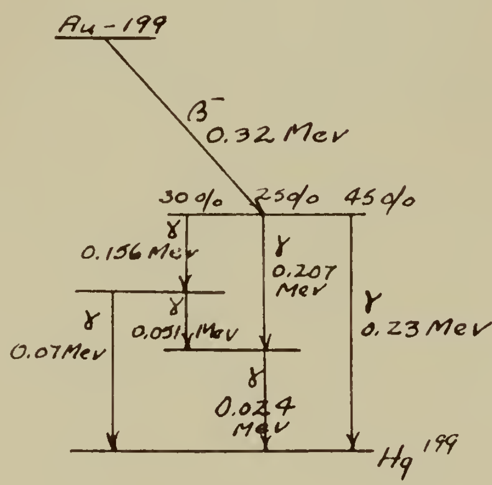
III. PROPERTIES OF Au-198

The isotope Au-198, or gold-198, refers to $_{79}Au^{198}$. It is artifically produced in the nuclear reactor at Oak Ridge, Tennessee, by neutron bombardment of $_{79}Au^{197}$ (stable). The gold-198 has a half-life of 2.7 days as previously reported (5), and two primary emissions. These are a beta particle of 0.97 Mev and a succeeding gamma ray of 0.411 Mev. Other secondary emissions have been reported in small percentages and there have been many conflicting papers on this subject as summarized by Colmery (5). The most recent information (6,7) available indicates the following decay schemes for the isotopes, Au-198 and Au-199.

FIGURE I

DECAY SCHEMES OF Au-198 and Au-199





Since the radioactive Au-198 is produced by neutron capture, there is a possibility of the formation of Au-199

by successive neutron capture. In his summary, Colmery (5), indicated that Au-198 has a slow neutron capture cross-section of 1.6×10^4 barns. Hill (8,9) has reported the presence of Au-199 along with pertinent information on the populations and ratios of the radiations. These are as follows:

$$\frac{\text{Au-198}}{\text{Au-199}} \cong \frac{95}{1} \qquad \frac{N_\gamma\ 411}{N_\gamma\ 159} \cong \frac{750}{1}$$

$$\text{Branching ratio} \quad \frac{159\ \gamma}{209\ \gamma} = \frac{2}{1}$$

These values are used in succeeding pages in calculating the energy emitted by seeds.

Gold wire and tubing used in these studies were purchased from the American Platinum Works, of Newark, New Jersey. The company reported (10) that the gold stock was mint gold 999.75. Thus there is a very small contaminant present. Information on the physical properties has been thoroughly covered (5) and will not be repeated here.

IV. SEED PREPARATION AND CHARACTERISTICS

GENERAL

During the preceding year only one size of gold wire was used in research. This wire was 0.007" in diameter and was enclosed in gold tubing of O.D., 0.032" and I.D., 0.015". No trouble was experienced in insertion of six centimeter lengths of the radioactive wire into the gold tube with the aid of tongs. The tubing thickness necessary was computed (5) using Feather's range equation (26) for beta particles, $R(gm/cm^2) = 0.542E(\text{in Mev}) - 0.133$. This gave a range R of 392 mg/cm^2 for 0.97 Mev electrons. The wall thickness used was 8.5 mils or 417 mg/cm^2. This wall thickness provided sufficient metal to eliminate the beta radiation, theoretically. However, this equation was based on aluminum as an absorber and it was felt the gold shield might be made in a thinner section. This was one point of investigation prior to selecting a new tubing size for further work. In addition, it was desired to accumulate data on different wire sizes as to activity and uniformity.

Along with the above, it would be necessary to improve on the method of calibration since previously a comparison with radium was made, using an electroscope. This was not an accurate method of calibration for several reasons (5) and could lead to erroneous dosage values. Another point of investigation was the method for cutting the sources. It was desirable to test the same cutting

device as used previously to improve the seed uniformity and allow quicker seed preparation.

Thus, the investigation of the above would provide considerable information on the gold itself and the physical handling and preparation problems involved.

BETA SHIELD

THEORY

As mentioned, the previous tubing thickness had been based on Feather's range equation for aluminum. This establishes a range of 392 mg/cm^2 of Al for 0.97 Mev beta particles and the gold shield used was 417 mg/cm^2. Thus, it would appear that the tubing would be more than sufficient to eliminate the beta radiation. In order to check this, absorption studies were made using aluminum, platinum, gold and lead absorbers. A drop of gold colloid was used as a source. Further, the literature was searched for information on the range of beta particles in various media. Very little quantitative information was found on materials other than aluminum, this being the absorber used universally. Comments on the theory of absorption are appropriate and will be included at this time.

Since gold is a denser material than aluminum, it might be expected that a smaller thickness in mg/cm^2 would be required. However, this is not the case. In stopping beta particles in a given material, the energy may be

lost by several processes. These include nuclear excitation, radiation, and ionization. Heitler (12) reports that for beta energies less than 5 mc^2, corresponding to about 2.5 Mev, the ionization loss is the most important effect. This is confirmed by The Science and Engineering of Nuclear Power (13). The ratio of radiative to ionization loss in a gold shield is about 1/11 for the energy of gold betas. As the ionization loss depends on the electron density or Z/A (14), this loss will be less for elements with a high Z number. Rutherford et al (14, p.427) state:

> "for equal superficial masses the heavier elements showed a smaller stopping power than the light elements."

Experimentally this group found a considerable difference in stopping power between aluminum and gold. A comparison of Z/A for the absorbers used is given below.

TABLE I

COMPARISON OF Z/A FOR ABSORBERS

Element	Z	A*	Z/A	Ratio to Al
Al	13	27	.481	1.0
Pt	78	195	.400	0.831
Au	79	197	.401	0.832
Pb	82	208	.394	0.819

* Number of most abundant isotope.

These values would indicate a 17-18% difference in range between the heavy group and aluminum. However, it must be remembered that the rate of energy loss is

for the actual path in the material. This path of the electron is considerably different from the perpendicular distance through the absorber, which is the actual shield thickness in most cases. It is reasonable to assume, though, that the range increases with increasing Z number. As an example, Glendenin (15) reported a range in aluminum of 400 mg/cm^2 versus approximately 500 mg/cm^2 in gold for a 1 Mev beta particle. The gold beta particles of 0.97 Mev would have slightly less range.

Several other references indicated the loss of stopping power with increasing Z. Morgan (16) divided the effects on range into variations in relative mass stopping power and scattering. The relative mass stopping power is a measure of the ionization loss and scattering is included as a constant multiplier determined by the physical conditions. The work on this analysis has not been completed by Morgan but the effect on range is apparently the same. One other point of interest is the fact that straggling occurs around the end point. The equations describing energy loss along an electron track refer to average values. As there is a distribution around the mean, straggling will occur. Thus, there will be no sharp cut-off point. The general conclusions, drawn from the literature, were that the gold shield thickness required might be considerably greater than the computed value.

ABSORPTION EXPERIMENTS

The calculations above based on theory were supplemented by the absorption studies previously mentioned. Several studies were made using the procedure and methods given in Appendix I. Ranges were determined visually and averaged. A total of eleven runs were made, divided as follows among the various absorbers.

TABLE II

ABSORPTION STUDIES

Absorber	Z	Runs	Visual Range-mg/cm^2
Al	13	4	402
Pt	78	2	$\sim$ 440
Au	79	3	435
Pb	82	2	$\sim$ 470

The visual range is the range of beta particles in an absorber as determined by visual inspection of the absorption plot.

The ranges for platinum and lead are listed as approximate because of the nature of the data. With the disk thicknesses on hand, it was not possible by combination to take enough points around the cut off thicknesses. Several plots were made with the data taken and the results averaged. However, the results still are only approximate. The ranges taken are in the order of the variation in Z/A.

The results obtained for the absorbers, other than aluminum, are undoubtedly low. The aluminum has a much

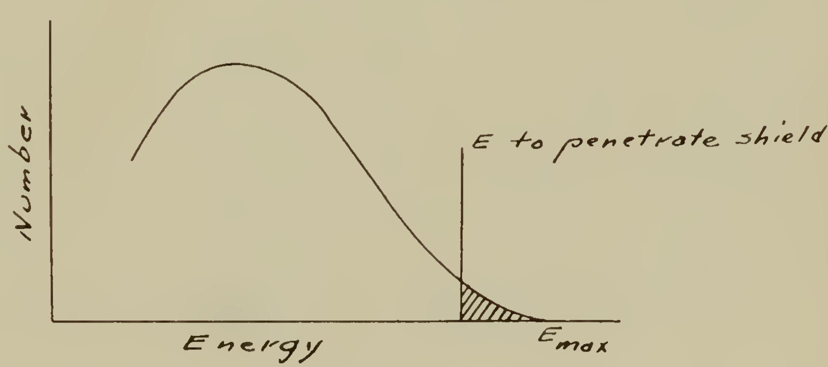
sharper cut off point and compares favorably with the Feather range of 392 mg/cm^2. Comparing the range in gold with Glendenin's (15) data indicates that the visual range is about 10% low. This is caused by straggling and the fact that the end point is obscured by the gamma activity. A better range determination could be made by making a Feather plot. Since the information secured was to be used on a qualitative basis only, this was not considered necessary.

COMMENTS ON THE RESULTS

Upon completion of these investigations, it was apparent that the tubing used had been insufficient to stop all beta particles. Thus, some particles would pass through the shield into the tissue. This would be in addition to leakage at the ends. Since the beta particles are not monoergic but have an energy distribution, only a small fraction close to the maximum energy will escape as shown by the shaded area in the figure below.

FIGURE II

ENERGY DISTRIBUTION OF BETA PARTICLES



$\frac{\text{Shaded Area}}{\text{Total Area}}$ = fraction of beta particles which penetrate through 0.020 cm of gold.

This is not serious as the gamma dosage close to the seed is very high and the tissue is killed in either case. The beta effect is restricted in scope, as Morgan (16) quotes the range in tissue of a 1 Mev beta particle as 0.42 centimeters with a half thickness of about 0.04 centimeters. Thus, a large part of the energy is dissipated immediately adjacent to the seed.

WIRE AND TUBING SIZES

TUBING

After completion of the above, a selection of tubing size was made. It was desired to keep the diameter as small as possible consistent with the shield requirements. This would allow smaller trocars to be used in insertion or the seeds could be used with nylon tubing and sewn into place. After consideration, a shield thickness of 0.020 cm was selected. This corresponds to 386 mg/cm^2 which is even less than the tubing used previously. However, it was felt that the beta leakage and effect would be localized and insignificant compared to the gamma field. The tubing size selected was O.D. 0.070 cm, I.D. 0.030 cm. After receipt of this tubing, two beta absorption studies were made using a radioactive gold seed as a source and the procedure as given in Appendix I.

In one, the ends of the seed were bare. A total range of 200 mg/cm^2 in aluminum was observed. Only a weak beta curve was found. The ratio of beta/gamma activity was 1.9. Since this activity included betas from the thinned part of the shield at the ends, another run was made using a one centimeter seed with the ends embedded in paraffin. Here only betas directly through the shield were observed. In this case a range of 90 mg/cm^2 of aluminum was observed. The ratio of beta/gamma activity was 0.5. Thus, the beta particles escaping through the side of the tubing were small in numbers and effect. By Feather's range equation, the energies corresponding to 200 and 90 mg/cm^2 of aluminum are respectively 0.60 Mev and 0.33 Mev. These particles would have a very low range in tissue. The effect of the escape at the ends of the seeds was investigated by Colmery (5) and was not considered serious. Thus, the tubing thickness selected is considered to be adequate for the purpose intended and the effect of the betas escaping may be neglected.

Reducing the shield thickness will have other slight effects also. For example, the X-ray production will be slightly reduced. Also, the gamma energy escaping will be increased so the net effect will be to offset other changes. In the evaluation of the effect of Compton scattering (5), the 0.411 Mev gamma ray was considered as 100% of the radiation. The minor effects are at low

energies with high absorption coefficients so they will be localized. Finally, in computing the dosage, an activity parameter is used in that the seed activity in mrhm/cm is determined by measurement. This will include any stray effects.

WIRE

In order to have as much flexibility in dosage as possible in treatment, different wire sizes could be used. Four sizes were selected for experimentation. These were 0.004", 0.005", 0.006" and 0.007" in diameter. Wires of different diameters could be irradiated at the same time. These would provide a spread of activities so that any case at hand could be readily accomodated. These sizes were irradiated and then analyzed as given on succeeding pages.

TOLERANCES

Since all manufactured articles are inexact in size some variations could be expected. Wire and tubing as purchased were within the following tolerances as given by the manufacturer (17).

"Within commercial tolerances"
Tubing diameters - ±0.0025 cm.
Wire diameters - ±0.0005 cm.

The tubing variations will increase or decrease the shield thickness slightly and make no appreciable difference in beta leakage. Errors in the wire diameters will result in variation in activity which is a measured quantity.

Thus, unless this varies from seed to seed cut along the wire this effect can be neglected. This was one point of investigation.

PREPARATION AND SHIPMENT OF IRRADIATION SAMPLES

Samples of wire were forwarded from time to time to Oak Ridge for irradiation. A standard aluminum irradiation can was used. Eight centimeter lengths of wire were cut. These were straightened carefully, the ends smoothed; they were then washed in acetone and weighed to 0.1 mg. In addition short sections of tubing were treated in the same fashion and irradiated at the same time. The irradiation cans were washed with acetone, and their tops sealed on by cellophane tape. Shipments were marked fragile and sent by first class mail. Shipments varied in weight from 137 to 187 mg. A total of four were prepared and irradiated.

The time involved for each shipment was about two weeks. Cans were irradiated for one week in the nuclear reactor. Upon removal on Monday mornings, they were packed and forwarded by air express, arriving at the laboratory on Tuesday afternoons. Three shipments were received in non-returnable containers. The other (187 mg) was in a returnable container. Each shipment involved a $10.00 handling charge at Oak Ridge plus express charges which depended on the type of container. Express charges for non-returnable containers were $3.07.

CALIBRATION OF THE SEEDS

GENERAL

As mentioned previously, calibration in the past consisted in comparing a gold seed with a radium standard using a Henson electroscope. In order to improve on this, it was decided to use a Victoreen Condenser r-Meter, Model 70, Serial 1618, OSU 164516, with 250 milliroentgen chamber. This instrument was serviced and recalibrated in January, 1952, by the Victoreen Instrument Company and upon return was used for many comparisons. To be suitable for comparison of different sources, a meter should be energy independent in the range of gamma energies encountered and have good accuracy. The data on the meter used as furnished by the company (18) are as follows:

Accuracy - ± 10%
Reproducibility - ± 3%
Energy dependence - less than 10% from 50 Kev. to 400 Kev.

For other measurements, chambers of 25 r, 100 r and 250 r were furnished. These are accurate to ± 2% of full scale reading. Originally it had been planned to secure a standardized gold source from the National Bureau of Standards for calibration of laboratory instruments. However, only a 15% accuracy was promised and since the above provides as good a measurement, no source was obtained. The Au-198 gamma energies are slightly above 400 Kev.; however, the meter was considered suitable for

experimental purposes. As the use of gold increases, additional effort could be expended in improving the calibration of sources.

In addition to the calibration of gold seeds, some comparative studies were made using a 9.54 mg radium standard enclosed in 0.5 mm of platinum. This gave a dose rate of 8.014 mrhm in air.

PHYSICAL ARRANGEMENT

A large ringstand was used in positioning the sources and chamber. A ring of about 6" diameter was securely clamped at the top of the stand and its position marked. This ring was covered with a piece of nylon net drawn very tight. A slotted piece of filter paper was secured in the center of the ring on the nylon. The slot allowed accurate and reproducible seed positioning. Since the ring was large and the weight of nylon negligible, scattering at the source was reduced to a minimum.

The 250 mr chamber was positioned below the source at a final distance of about 25 centimeters. This position was determined after several trial runs. The chamber has a metal extension about 2 centimeters in diameter and 10 centimeters long. A test tube slightly larger than this was securely clamped to the stand. The chamber was then positioned by sliding the metal extension into this test tube. Rubber rings from finger cots were placed on the extension to insure a tight fit. The test tube was

positioned so that the chamber was centered and aligned under the linear source. This method of positioning allowed accurate and quick placement of the chamber and easy removal so that errors in time measurements were small. Repeated measurements were made to insure that the geometry was reproducible.

MEASUREMENTS

A number of runs were made using the mount described and the radium source. In practice, the source was positioned. Then the chamber was charged and slid into the test tube. At the same time an electric timer was started. Runs were made for one-half, or one hour. With the radium, good agreement was reached between the calculated and the measured dose. The gold seeds were measured in exactly the same fashion. The meter reading corrected for temperature and barometric pressure was used as the basis for calibration of the gold seeds. Data taken on the seeds are included in Appendix II.

COMMENTS ON THE METHOD

From the work done thus far, it is apparent that the method is simple and fairly quick. The accuracy is good. Points of error are the large size of the chamber and short distances used. If a small thimble chamber of the same range could be procured it would give a better measurement. Due to the low source strengths, the chamber must be fairly close to secure a reasonable deflection

in 1 - 2 hours. This leads to geometry problems. With a small chamber with a range of say 25 mr, a much better arrangement would result. However, the method used is practical and easy. In the future when usage increases, a refined and more rapid method should be developed.

ELECTROSCOPE CALIBRATIONS

In order to have a quicker method available, a laboratory electroscope was calibrated. This instrument was a Quartz Fiber Electroscope, Model 2, Serial 124, OSU 182712, manufactured by the F. C. Henson Co., Pasadena, California. It was positioned on the same ringstand as before with the chamber directly under the seed to be measured. The distance from the source to the base of the ringstand was 72.5 centimeters.

Readings were taken on seeds from three of the gold shipments received to develop a calibration curve. These seeds had been calibrated using the Victoreen instrument. After taking a series of readings, all data were plotted as mrhm versus the rate of discharge of the electroscope. This gave a straight line at the lower activities with a slight curve developing at the higher rates. Data among the three shipments checked very well. All data and the calibration curve are included in Appendix II and apply only to the particular physical arrangement used.

SEED CUTTING

Seeds were prepared using the same devices and tech-

nique as before (5). After loading the radioactive gold wire into a section of tubing, it was pinched off into pieces one and two centimeters long for calibration and comparative studies. The first two shipments were cut exactly as before with the blank at the end of the cutting device opposite that of the micrometer. The last two shipments were prepared and then seeds were cut at the micrometer end of the cutter shield. In order to accomplish this, it was necessary to establish the cutting correction involved. This was done by cutting fifty non-radioactive samples in various lengths. These were cut with micrometer settings increasing in one quarter centimeter increments. These seeds were weighed individually. The average length of each group was then computed and a plot made of micrometer setting versus seed length. This gave a straight line with an intercept at a seed length of 0.15 centimeters. Thus, the cutting correction was established as this value. Data taken and the plotted figure are given in Appendix II.

During the hot runs, the first few loadings caused trouble, mainly due to inexperience in handling. However, after practice, it was possible to load a section of tubing in a very short time, using the tongs as before. It was found that seed cutting at the micrometer end of the device was easier, faster, gave less radiation exposure and resulted in more uniform seeds. For a given length

of seed only one micrometer setting was necessary, whereas, with the previous method it was necessary to change the spacer and make a new micrometer setting for each seed cut. Thus, the improved method should be used for future work.

When the radioactive gold is applied in therapy, it will be necessary further to refine the method. The existing device will handle seeds up to 2.5 centimeters in length. In cancer therapy it will be necessary to use many seeds with lengths up to perhaps 10 centimeters. Thus, some automatic and improved device will be necessary.

One other point of interest is the length of wire used. Eight centimeter sections were irradiated and then slipped into sections of tubing. These could be cut into seven seeds one centimeter long without difficulty, and the remainder was discarded. For long seeds, long sections of wire will be required. This will require a rather stiff wire and also tubing with a substantial clearance. It was found that the 7 mil wire occasionally gave trouble during insertion into the I.D. 0.030 cm. tubing due to the small clearance involved. Also the smaller wire sizes were prone to bend too easily for facile handling. Thus it is apparent that tubing used in the future should be of such size as to give a relatively loose fit and the wire should be stiff enough to be loaded into sections up to 20 - 30 centimeters or more long.

A length of wire 20 - 30 centimeters long may be easily irradiated in the standard irradiation can without shielding. This can be accomplished by winding the wire around a pencil or other cylindrical form. The gold wire is ductile and permanently deforms so that a short spring is formed which will fit into the irradiation can. Since all turns are separated, there is no shielding by the gold itself. The coiling does not prevent loading into sections of tubing upon return since the wire may be easily straightened prior to insertion.

ACTIVITY OF DIFFERENT SIZES OF WIRE

During irradiation at Oak Ridge, the wire sections are continually bombarded by neutrons. These are captured by the stable gold nuclei which are then converted to Au-198. It was felt that the relative activity among wire sizes might vary due to self shielding in the larger sizes. Accordingly, the last three shipments to Oak Ridge contained sections of wire 4, 5, 6 and 7 mils in diameter. In addition, small sections of tubing were enclosed for irradiation. These were of O.D. 0.021" and O.D. 0.070 cm. Upon return the activity per milligram was compared using the methods given in Appendix II. Results are summarized below from data given in Appendix II.

TABLE III

COMPARISON OF WIRE ACTIVITIES

Sample	Diameter	Shipment Number 2	3	4
Wire	0.007"	1.0	1.0	1.0
Wire	0.006"	- -	0.91	0.93
Wire	0.005"	0.84	0.78	0.77
Wire	0.004"	1.02	0.92	0.92
Tubing	O.D. 0.021" I.D. 0.005"	0.72	0.77	- -
Tubing	O.D. 0.070 cm I.D. 0.030 cm	- -	- -	0.75

Note: The tabulated value is the relative activity per milligram of active gold expressed in arbitrary units. The activity of 7 mil wire was taken as 1.0.

The values for the 4, 5 and 6 mil wire are not what would be expected since the center of the larger 7 mil size should be shielded to a greater degree. Two reasons are advanced for the lesser activity. One of these lies with the manufacturing tolerances involved. There is enough size variation due to the tolerances to account for most of the reported values. In addition, it may be that the 7 mil or some larger size wire represents an optimum size for irradiation. The reduced tubing activity is apparently due to self shielding. In any event, the activities are not greatly different from that of the 7 mil wire.

UNIFORMITY OF SEEDS

All of the seeds which had been prepared were measured to determine the uniformity of the activity. These com-

parisons indicated both the accuracy and reproducibility of the cutting method and also variations in wire size along each section. Since it is desired to have a group of seeds as uniform in size as possible, it is necessary to insure that the wire is uniform enough to satisfy this requirement. Also, the cutting technique should provide accuracy and reproducibility.

The cutting correction for the micrometer end was determined to be (-) 0.15 centimeters. Thus seeds of one centimeter would be cut with a micrometer setting of 0.85. The last two shipments were cut in this manner and these, along with seeds from the second shipment, were used in the calibration of the electroscope. A straight line plot resulted from the data taken using two seed sizes in varying combinations. This line passed through the zero point thus indicating the cutting correction was accurate.

The comparative measurements were analyzed, using small sample theory as given in Hoel (19). These data indicated that cutting seeds at the micrometer end of the cutter shield resulted in smaller errors. In addition, no great differences were found in a group, thus indicating that the wire used was essentially uniform. The following results are summarized from data given in Appendix II.

TABLE IV

SEED COMPARISONS

Wire Dia. Mils	Length of Seed in cm.	Number of Seeds	Shipment No.	σ cm	Max. % Variation from mean
7	1	3	2	0.109	10.9 *
5	1	5	2	0.047	6.3 *
4	1	6	2	0.036	5.5 *
7	2	2	3	0.0	0.0
6	1	7	3	0.020	3.2
5	1	5	3	0.017	2.5
4	1	7	3	0.001	2.4
7	1	2	4	0.025	1.8
7	2	2	4	0.013	0.9
6	1	7	4	0.015	2.5
5	1	7	4	0.019	3.0
4	1	7	4	0.014	2.2

* These seeds were cut by the original method.

The remainder were cut using the new technique.

Inspection of these values indicates that the seeds and wire are fairly uniform. In all, the results with a total of sixty seeds are given above. It is to be noted that the new technique gives much better results than the old.

V. DOSAGE CALCULATIONS

GENERAL

In order to apply linear sources interstitially, it is necessary to know the dose supplied at points in the surrounding tissue. Since the dose delivered cannot be measured in place, it is necessary to rely on a calculated value based on the geometry involved and the activity of the source. The dose delivered at point P, removed from the source may be calculated after certain assumptions are made concerning scattering, path length, and shielding, among others. These assumptions are necessary since some of the effects of radiation in tissue cannot be evaluated. In the case of the gold-198, the calculations are further complicated by the decay of activity during the time of exposure. With radium or cobalt, the activity is constant during the irradiation time. However, with gold-198, the activity decreases to such an extent that in 9 days, 90% of the activity has decayed. In therapeutic applications, it is desirable to have a dosage chart or table at hand so that dosages may be computed readily. Further, as with radium, it is desirable to have the dosage given by certain seed patterns tabulated and immediately available. Before going to complex arrangements, however, it is necessary to develop a diagram or table for the dosage at a point P, removed from a linear source.

LINEAR SOURCES

ASSUMPTIONS

In dealing with the gold linear sources, certain assumptions must be made. For one, the gold wire is not a true line source, but has finite dimensions. A photon, originating in the wire, passes through part of the wire, the tubing, and a certain tissue thickness before arriving at P. In the evaluation, all photons are assumed to originate on the center line of the wire. This corresponds to the average condition. The gold wire and tubing are assumed to be constant in size and manufacturing tolerances are neglected. Thus, the seeds are assumed to have a uniform activity. The seed statistics of the previous section indicated this was reasonable.

The decay schemes of Au-198 and Au-199 indicate a variety of beta particles and gamma rays. It has previously been determined that there is about one percent of Au-199 formed in addition to the Au-198. An energy analysis was made by Colmery (5) who determined that only the primary gamma ray of 0.411 Mev was important in dosage calculations. Accordingly, all other radiations were neglected in the calculations. The beta particles were assumed to be completely shielded out. Colmery (5), also evaluated the effect of scattering in tissue. This also is neglected in the calculations.

Thus, it is assumed that 0.411 Mev photons are

emitted at the center of the wire, pass through the wire, the tubing, and the tissue and are absorbed at point P to give a certain effect. These are attenuated along the path traversed. The total absorption coefficient is used to evaluate this attenuation.

CALCULATIONS

A derivation of the equations for the dosage at point P is given in Appendix III. This consists of two parts. One is for points off the axis; the other for points on the axis and distant from the end of the seed. These derivations result in integrals that cannot be evaluated directly. Accordingly, the integrals were evaluated by numerical methods and the results are included in Appendix III in tabular and graphical form. In order to eliminate the time factor, the results were recorded in terms of a lifetime dose, i.e., the gold is left in situ for life. Actually, 99.9% of the dose is delivered in 27 days. One point of interest here is the effect of wire size. Since this enters into the attenuation factor, it was felt it might alter the dosage diagram to such an extent that a different diagram would be required for each size. Accordingly, calculations were made considering 4, 5 and 6 mil wire individually and were carried through to completion. After evaluation, it was found that one diagram would suffice for the four wire sizes on hand providing the same tubing thickness was used. However, if larger sizes are

employed in the future, say up to 15 mils, or if the tubing thickness is changed, the diagram should be redrawn to see if a significant difference results. The calculations are tedious but not difficult to accomplish.

RESULTS

Upon completion of the evaluation, the tabulated results were graphed into one dosage diagram. This is included in Appendix III. Using this figure it is possible immediately to determine the lifetime dose at P by positioning a replica of the seed at the proper place. The diagram is drawn for one side only and is a mirror image on the other side. Instructions for the use of the diagram are given in the appendix.

PATERSON PARKER SYSTEM

GENERAL

In applying linear sources interstitially, patterns of seeds are used. Depending on the tumor to be treated, these may cover a flat slab, cylinder or other volume. A considerable amount of work has been done in applying radium seeds interstitially. Since the original developments occurred many years ago, the procedures in applications of radium have been standardized and refined, and considerable data accumulated on the biological effects. The treatment method using radium sources is "The Manchester System" (20) as developed by Paterson and Parker

(20) et al. This system covers both moulds and interstitial implants using standardized patterns.

Originally, for experimental purposes, only the dosage diagrams for linear gold sources were developed. With these, small squares or rectangles on experimental animals could be treated by adding up the effects of each of the seeds through or surrounding the area. It was desired to set up a system for larger areas similar to the Manchester System since this has been proven by use to be a satisfactory one. Actually, as stated, many types of volumes must be analyzed in a complete treatment. However, this is an extensive task that must be carried out over a long period as treatment and use increases, so that satisfactory results may be obtained. The logical extension, at this stage was to analyze single plane interstitial implants for thin slab treatment. By extending this, thick slabs could then be treated. No attempt was made to go into more complex arrangements. Upon completion of the analysis for thin slabs treated by planar implants, a table was drawn up giving the initial linear gold activity necessary to treat the volume. This was expressed in terms of mrhm/cm per 1000 r of dose in a slab one centimeter thick with the plane of gold seeds bisecting the slab. A maximum area of 49 cm^2 was analyzed. This allows 7 cm seeds to be used. Since the gold tubing is soft and easily bent, it was felt that longer seeds should have

a different cover, say stainless steel. This of course would require a new analysis.

THE MANCHESTER SYSTEM

For single plane interstitial implants, radium seeds are arranged in various patterns depending on the area involved and the dose desired. Solution of the dosage problem have been tabulated in terms of milligram hours per 1000 r of delivered dose for various areas. Since radium has a constant activity, either the time or amount may be varied to suit the case at hand. The therapist decides on a suitable dose, the tumor is measured and then the number of mg-hrs computed to fulfill the requirements. Once this has been decided, the actual implantation is made in a certain pattern conforming to rules that have been based on calculation and experience. For a single plane implant, these are reproduced below as taken from the reference (20).

"DISTRIBUTION RULES FOR PLANAR IMPLANTS

1) The radium should be arranged on a single plane in such a way that for areas of under 25 sq. cm. two-thirds, for areas between 25 sq. cm. and 100 sq. cm. one-half, and for areas over 100 sq. cm. one-third of the total radium is round the periphery of the area, and the remainder spread evenly over the area itself.

2) A common arrangement will be found to be a row of parallel needles with active ends crossed by means of needles at right angles to the first part of the implant. Should it prove impossible to cross ends of such an implant 10 per cent must be deducted from the area of the plane for table reading purposes, for each "uncrossed" end.

3) Needles arranged as such a series of parallel lines should not be more than 1 cm. from each other or from the crossing ends. Similarly the spacing of "seeds" should not exceed 1 cm. from each other.

4) In two plane implants the radium on each plane should be arranged as in (1), (2), and (3) and the planes should be parallel to each other.

5) If two planes differ in area, the area to be used for dosage-table purposes is the average of the two, and the total radium is thereafter divided pro rata to each area."

These rules have been established following extensive calculation to determine the most advantageous source distribution. Due to the inhomogeneity, the radiation field will not be uniform but will vary by as much as $\pm$ 10%, except close around the sources where the dose will be very high. Since radium is available in sources of different linear density, some leeway is available in the placement of sources. Thus, the density within the mass and surrounding the mass may be varied.

ADAPTATION TO GOLD-198 SOURCES

Two differences are immediately apparent when one considers the application of gold-198 sources in a similar system. One is the fact that the activity is not constant but rapidly decreases with time. Another is that the gold is used in a single size so that only a single linear activity is available. Due to the short half-life, the tabulated value cannot be set up as with radium. Instead, it is necessary to compute an initial activity

per centimeter for a specified treatment time and pattern. Actually, there is little difference in the final result since this activity may be altered by a correction factor if a different treatment time is desired. The fact that only a single linear strength is considered results in a modification of the implantation rules as given below. The general pattern,however,still conforms to that for radium.

RULES FOR APPLICATION OF Au-198

These rules were established prior to the mathematical analysis as a basis for the evaluation:

1) Use a single linear source strength in the pattern.
2) The seeds shall be spaced at 1 cm intervals in the plane and parallel to each other. The open ends shall be crossed by similar seeds at right angles to the others so that the periphery is completely enclosed.
3) Seeds shall be inserted parallel to the long axis of a rectangle.
4) Care must be taken to avoid uncrossed ends.

The Manchester System (20) gives a number of rules for uncrossed ends and for two plane implants. Since the gold varies from radium as given above, these additional rules adapted to gold will require further analysis.

CALCULATIONS

Since a tumor occupies a volume and the seeds are in a plane, it is necessary to compute the minimum dose within a slab of tissue surrounding the plane in which the seeds are placed. In accomplishing this for radium, a choice of one half centimeter from the plane of seeds was established as a treating distance. This was clinically satisfactory so the development here proceeded on that basis. The seed pattern, therefore, when so placed irradiates a flat slab of tissue one centimeter thick. In the development for radium, absorption and scattering in tissue were neglected and the emission of beta particles ignored. In applying the method to gold-198, absorption in the gold shield and tissue is considered but scattering and beta emission are neglected.

In proceeding with the computation, the first task was to tabulate the lifetime dosage for various positions about a one mrhm/cm linear gold source. This data sheet is included in Appendix III. Accumulation of these data involved the solution of the dosage equation for the odd distances involved since it was desired to have the values as accurate as possible. Upon completion, it was then possible to take an area with a particular grid system and to compute the dose at individual points. For each area chosen, the lifetime dose was computed at points spaced one-half centimeter apart. During these

computations, it became apparent that some transitory boundary area was necessary around the tumor. In the examples (20), a one centimeter boundary was used. This was incorporated in the solution for gold. Thus, a 3 cm x 3 cm tumor would be treated by a 5 cm x 5 cm grid for example. When all points within the treatment area had been computed, the one with minimum dose was selected. This dose was used to find the mrhm/cm/1000 r for the particular area for a lifetime implant. After completion, corrections were applied for various shorter treatment times. These values are tabulated in Appendix III. Also included are a decay curve for Au-198 and a curve giving the per cent of activity used.

COMMENTS ON THE RESULTS

These tabulated values may be used for single plane implants. For two plane implants at varying distances, correction factors will be necessary. To determine these factors will require a solution for varying distances and then comparison with the original results. These can then be combined in the analysis for thick slabs. It is not believed the correction factors of the Manchester System (20) are directly applicable to gold, though there probably will not be too much variation from them. This problem remains for solution along with the extension to other volumes. One other point of interest is that the solutions presently determined can be used for planar mould

treatments with a one-half centimeter treatment distance. However, the main application of the gold would be in tissue implants where the sources could be left in place permanently.

VI. ISODOSE LINES

GENERAL

Isodose line diagrams are useful to indicate the evenness of a radiation field and its extent. Accordingly, isodose lines were determined for typical gold seeds. These may be determined in two ways; by calculation and by experiment. Calculated lines were determined using the dosage values derived for linear sources. Experimentally, lines may be determined by instrument measurements using a phantom and small chamber or by autoradiographs. After calculating the lines about several seeds, it was decided to use the autoradiograph technique since very small distances were involved. No instrument sufficiently small to make the measurements was available. The isodose lines were determined in terms of lifetime dose in roentgens due to the gamma activity of a 1 mrhm/cm seed.

CALCULATED ISODOSE LINES

A total of three seeds were analyzed by this method. One of these was analyzed using the dosage diagram derived by Colmery (5). Only the lines about the center of the seed were determined. The remaining two analyses were based on data assembled during this research and are complete.

To compute the isodose lines, a start was made with the dosage diagram for a linear source. With a seed replica placed in various positions, the lifetime dose

at point P was determined. This was done for points on the perpendicular bisector of the seed and then on lines parallel to the bisector and spaced in increments of 0.25 centimeters. Within the scope of the diagram, it was possible to compute values on many points in an area about as wide as the seed length. These values were not in even numbers of roentgens. For these parallel lines, the dose was plotted versus position off the axis. From this set of graphs, the positions for various selected roentgen dosages were determined and recorded.

It was not possible to calculate the dose at points close around the end of the seed using the diagram. Instead, it was necessary to pick a particular point close to the end of the seed and then compute the dose using the values assembled in the numerical integration. In order to standardize the method, points were picked along lines parallel and perpendicular to the seed. After calculating values on many points, the dosage values were plotted against position and the points on the isodose lines connected by a continuous line were determined. Still one set of points then remained to be determined; those on the axis of the seed and distant from the end. An integral was developed for this case and evaluated numerically (section V). Morgan (16) indicated the form had previously been solved by Gold but his factors were not used in the evaluation. Results indicated that only

a short portion of the seed was effective in producing a dose at a point on the axis because the remainder of the seed was shielded by itself. The evaluation of the integral depended on the shield thickness at the end. This thickness was uncertain but certainly was less than the tubing thickness. It was taken as zero initially and then the values corrected for various thicknesses to see how they would fit with the remaining points.

When drawn, the isodose lines formed a regular pattern with a reversed curvature at the end of the seed. Examination of autoradiographs made with active seeds indicated the same curvature. Thus, the form is accurate. The radiation field around the end of the seed is restricted due to the shielding and, therefore, care must be taken to avoid uncrossed ends in an implantation. Diagrams of the calculated isodose lines are included in Appendix IV.

AUTORADIOGRAPH STUDIES

GENERAL

It was desired to determine the isodose lines about one seed by physical measurements to supplement the calculated diagrams. Originally as stated, it was planned to use a small chamber and to determine the lines by measurements made in a water phantom. This method was abandoned after the calculations were completed since no

suitable chamber was available. Instead, it was decided to use the autoradiograph technique in the determinations, In this method, exposed film is developed and the radiation field analyzed using a photo-densitometer.

AUTORADIOGRAPH TECHNIQUE

Autoradiographs of typical sources of 7 mil wire were made using both lantern slides and X-ray film. Kodak Lantern Slide Contrast Anti-Abrasion Plates were used along with DuPont X-ray film, Xtra Fast, type 508. The lantern slides were exposed to get a qualitative indication of beta leakage at the ends of the seeds. The X-ray film was used for the analysis of the isodose lines.

X-ray film was prepared in the dark room. Standard 8" x10" sheets were cut into pieces about 3" x 4". These were exposed individually and in a stack to determine the beta penetration. Exposures were made with various seed lengths and for increasing times up to 10 minutes. A template was used to hold the seed against the film. It was constructed of cardboard stapled to a wooden handle. A groove was cut in the face of the cardboard to hold the seed. The seed was held in place by cellophane tape. Protruding ends of the wooden handle allowed quick and easy handling and good positioning. During exposure the template was placed face down against the film which was placed on a wooden table. The backscatter in the wood should approximate that in tissue.

DEVELOPING TECHNIQUE

Materials used were as follows:

Developer - High Contrast Developer
Formula D - 19
Lot No. 22M245C 154

Fix - Acid Hardening Fixing Bath
EK Co. Formula F 5
Lot No. 23M 714C 227

These were procured through the university laboratory supply system and were manufactured on campus.

The following procedure was used in handling the film and plates:

Developer - X-ray film - 3 minutes
Lantern Slides - 4 minutes

Wash - Dilute acetic acid - 15 sec.

Fix - 15 minutes

Rinse - 1 hour

Agitation - By hand

Except for the final rinse, the procedure was carried out at room temperature, $\sim 22^{o}$C.

ANALYSIS

Lantern slides exposed in the above fashion showed strong localized beta leakage at the ends of the seeds. This leakage would tend to extend the radiation field at the ends and thereby improve the distribution. The actual isodose lines would be farther from the ends of

the seed than the calculated ones due to scattering and the beta radiation.

From the group of X-ray film exposures on hand, one film was selected for analysis by the photo-densitometer. This film was an exposure of a 2 centimeter source that showed no beta leakage and, therefore, recorded only the gamma effect. This was desired so as to have data comparable to that calculated. After selection, the film was mounted in a paper template. A grid system was then laid off on the film and template to assist in positioning and recording the density. A Weston Photographic Analyser was used for the density measurements. Specifications on this instrument are as follows:

Weston Photographic Analyser
Model 887, Serial 2636, OSU 215076
Operating Voltage - 105 - 120V
Cycles 50 - 60, 50 watts.

In addition, a Weston external meter, Model 273, Serial 47461, was used with the analyser.

The analyser has a light aperture of 0.062" = 1.57 mm. Thus, readings were taken of a small area at each point of the grid which is considered to be a point value in the analysis. By means of the grid system, the film was positioned over the light aperture and readings of the density were then taken. The grid had been so drawn as to include all four quadrants of the seed. Readings

were taken at corresponding grid points in all quadrants. These readings were then averaged to have one set of values for a quadrant. After averaging, these values were used to determine the positions of the isodose lines.

Conversion of densitometer reading to dose in roentgens was accomplished by using the calculated dosage values. It was desired to have the isodose lines expressed in terms of lifetime dose in roentgens. As with other calibration methods, the measurement had to be referred back to a calculated value of some standard. Here the calculated dosage values for gold was used. Choosing the perpendicular bisector of the seed as a base line, the position was determined of the points corresponding to selected lifetime dose values. This gave one set of points. Correspondingly, for the same line, densitometer readings were determined for the same points. Thus, comparative figures were at hand giving the densitometer readings corresponding to selected dose values. Using these density values, the isodose lines were traced out around the seed by graphing the remaining data and picking off the line locations corresponding to the established density values. Points establishing the lines have been tabulated and given, along with the diagram, in Appendix IV.

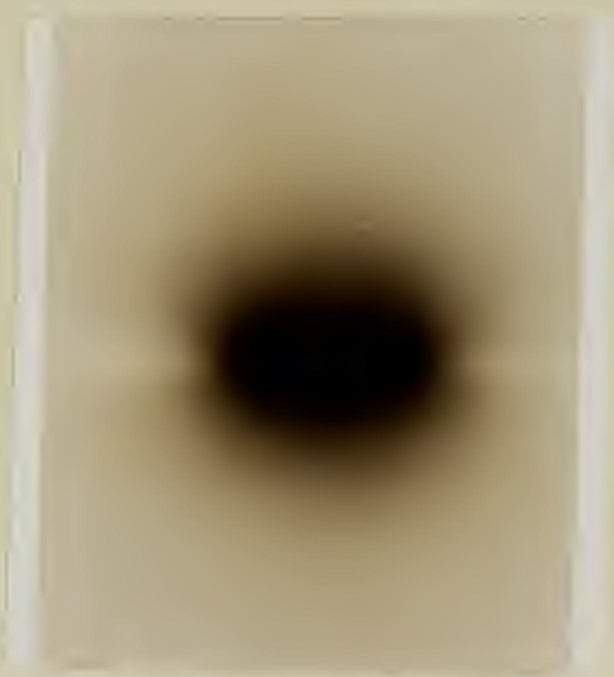
COMMENTS ON THE RESULTS

Analysis by this method gave the same type of isodose line diagram as that obtained by calculation.

The reverse curvature was present, though not as pronounced. This indicated that scattering and other effects improved the radiation field around the ends of the seeds. No great differences from the calculated values were noted. It is to be noted that the actual dose delivered to the X-ray film is unknown. This could be established in some future determination using controlled exposures and a film calibration. Since the therapist is concerned with the lifetime dose, this type of diagram is believed to be more suitable. At some time in the future, further work should be done using a small ionization chamber and tissue phantom to evaluate the secondary effects and to improve the calculation of dosage.

FIGURE III

AUTORADIOGRAPH OF A 2.0 cm GOLD-198 SEED



VII. RADON SEEDS

GENERAL

Radon is a gas produced in radium decay. It has a half life of 3.825 days which is somethat longer than gold. The gas is collected, diluted as necessary and pumped into gold tubing. This is then pinched off to produce the source strength desired. The seeds are used as high activity point sources for permanent implantation in tumors. The gamma rays emitted, which are the same as for radium, are the primary agents used in therapy.

During the research on gold application, twelve radon seeds were received in a group for comparison. Those seeds were about 4 mm in length and 0.5 mm in diameter and were of gold tubing. They were certified by the Radium Chemical Company, Inc., New York, N. Y., to have an average source strength of 1.46 mc at time of use, and had an activity of about 1.8 mc during the measurement. These seeds were sealed in a small-necked glass ampule and enclosed in a lead container and wooden box for shipment. They were kindly lent by Dr. A. G. James and were returned to him the following day.

RADON LEAKAGE

Since radon is a gas and since the seeds have pinched-off ends, the possibility of leakage exists. This is disadvantageous since it results in a seed of low activity unknown to the physician and also creates

personnel hazards. Upon receipt of the twelve seeds, the ampule was unpacked and removed with tongs. The end of the thin neck was broken off; the seeds were dumped into a shielded container; and the empty ampule quickly sealed in another bottle. This bottle was checked for the presence of radon gas using a laboratory monitor and geiger counter. No appreciable difference in background resulted, indicating that the seeds of the shipment on hand had not leaked. With the solid gold wire used in these investigations, such a problem does not exist.

SEED COMPARISONS

Since radon is a gas and since short seeds are difficult to cut with small tolerances, all seeds were measured for comparisons among themselves. To do this, a Tracerlab Autoscalar, OSU 238137, was used together with a Tracerlab Geiger Tube, type TGC-2, Serial 4D73, with 1.5 mg/cm^2 window. The tube was mounted at the top of a ringstand with window facing downward. The aluminum cap was left in place. Another ring was covered with a creased filter paper and clamped at the bottom of the stand. Radon seeds were positioned reproducibly in the creased portion.

Prior to the measurements, a plateau was run on the tube and the operating voltage established at 1400 V. Background was taken before and after the runs on the radon seeds and averaged. 4096 counts were used for each

measurement with a total of four measurements being made on each seed. For each reading, the scaler time was taken along with the scaler correction and clock time. Counts per second were then corrected for background and decay from zero time to bring all seeds to a comparable point.

A considerable variation in the activity was found. Corrected counts per second varied from a maximum of 118.1 to 176.1; a difference of 48. Thus, there were large percentage differences among the seeds. The mean was established at 136.2 c/s with a standard deviation of 18.2 c/s. Thus, the seeds at time of use varied from 1.27 mc to 1.79 mc. The gold seeds cut during these re-researches were much more even in activity and had relatively small differences. However, these seeds were much longer so that cutting errors should be less. The data and statistics on the radon seeds are included in Appendix V.

BETA LEAKAGE

Autoradiographs were made of all radon seeds using lantern slides and the procedures as previously given for gold seeds. One radon seed was compared to gold. Beta leakage was apparent at the ends of the seeds in the autoradiographs. Others indicated an unevenness in the field. However, this may have been due to faulty positioning.

Since the radium decay products emit hard beta particles, one of which has an energy of 3.15 Mev, and since the tubing had thin walls, it was felt there should be considerable beta leakage present. Accordingly, two beta absorption curves with aluminum absorbers were run, using the same technique as with the gold seeds. A range of 900 mg/cm^2 of Al was observed. The ratio of beta to gamma activity was 1.9. Thus, there was considerable beta leakage through the side of the seed. 900 mg/cm^2 of Al corresponds to a beta energy of 1.9 Mev. This would have a greater range in tissue than the gold betas. Thus, the beta effect would not be localized to as great a degree for these radon seeds. These seeds were typical of those in common use and undoubtedly beta leakage occurs in all such thin-walled seeds.

SEED ACTIVITY

The average activity of the radon seeds was certified to be 1.46 mc at time of use. Four seeds were grouped as a source and their activity checked with the 250 mr Victoreen chamber using the same calibration technique as that previously described for gold-198. The average activity determined for these four seeds was almost exactly twice the quoted value. No error in computation was apparent as the calculation involved only a simple ratio. In the measurements, no beta shield was used. Since there is considerable hard beta activity, this may

have influenced the reading.

The radon seeds were compared with the gold sources by calculation. One centimeter gold seeds of 7 mil wire, one half-life after removal from the pile at Oak Ridge, were comparable to 1.5 mc radon seeds. If shorter gold seeds of high activity were desired, however, a larger wire diameter would be required.

COMPARISON OF RADON AND Au-198 SOURCES

ADVANTAGES OF Au-198 SOURCES COMPARED WITH RADON SOURCES

1) Since gold wire is easily procurable and is irradiated in a nuclear reactor, no production plant is necessary. Radon production on the other hand requires a radium source with its attendant difficulties.

2) There is no contamination problem with radioactive gold wire. With radium and radon, however, the contamination problem is always present and must be guarded against. Furthermore, lost radioactive gold quickly decays, whereas a radium spill may result in permanent contamination.

3) Being in solid form, the gold-198 sources are not subject to loss of active material in processing. Radon sources, on the other hand, may leak gas and become relatively inactive.

4) Both gold-198 and radon sources show beta leakage. The beta particles from gold-198 sources are less energetic than those from radon sources of the type

used in these researches. Thus, the beta particles from gold-198 would be more localized in tissues.

5) The gold-198 sources prepared during these researches had a more uniform activity than the radon sources examined.

6) Since gold-198 has a less energetic gamma emission than radon, on the average, absorption coefficients in tissue will be greater for the gold. This means that the irradiation effect, using gold-198, will be localized in the tumor area to a greater degree than if radon were used.

7) The treatment time has an effect in radiation therapy since there is a recovery factor involved. Gold-198 has a shorter half-life than radon; the total dose will be delivered in a shorter time and the recovery factor will be less important.

8) Radon sources are received from the manufacturer with a specified average strength and may not be altered after receipt. Gold-198 sources, however, may be adjusted at the time of use by changing the wire size or length.

DISADVANTAGES OF Au-198 SOURCES COMPARED WITH RADON SOURCES

1) Radon emits the same radiation spectrum as radium. Any known radium source may be used as a standard in radon calibrations. No standard is available at present for gold-198 sources so that the calibrations

are not as accurate.

2) Radon sources are received by the therapist in a ready to use form. The gold-198 must be handled and sources prepared after irradiation in the nuclear reactor.

3) Unless special precautions are taken, self shielding of the gold wire may occur during irradiation in the nuclear reactor. This will result in occasional weak sources.

4) The gold-198 gamma rays may have a more pronounced effect on bone than radon emissions (5).

VIII. STAINLESS STEEL SHIELD

GENERAL

In order to treat large tumors with gold, long sources will be required. These may take several forms, such as short gold seeds placed successively, or shorter seeds enclosed in plastic thread. Another possibility would be the use of stainless steel tubing for long sources. This tubing itself could be used in insertion since it is very strong, even in small sizes. The gold wire would be en-closed as in the gold tubing.

DATA

The composition and properties of one stainless steel tubing sample currently on hand were unknown. The Metals Handbook, 1939 Edition (21) was used as a guide in selecting suitable data for calculation. There are many types of stainless steel, however, so that in the calculations below the following composition was chosen:

TABLE V

COMPOSITION OF STAINLESS STEEL

Element	%	Z Number	Atomic Weight
Fe	74	26	55.84
Cr	18	24	52.01
Ni	8	28	58.69

In addition to the above, there are trace elements in the alloy that are unimportant. The density of this steel is about 7.75 gm/cc and the elastic limit about 50,000 psi in the annealed condition. When properly

tempered, this limit may be greatly increased.

After completion of the calculations, a catalogue (22) on stainless steel products was received from the Superior Tube Company, Norristown, Pennsylvania. One suitable type was listed as in stock. It is presently used for hypodermic needles and should prove satisfactory in the future. Basic data on this steel are given below:

Stainless Steel, AISI type 304
Composition - 18% Cr, 8% Ni plus
trace elements
Annealed yield strength - 34/47000 psi
Ultimate strength - 100,000 psi
Density - 0.286 lb/in^3, 7.91 gm/cc.

The values assumed for the calculation check very will with these values so no changes will be made.

The Superior Tube Company was able to furnish type 304 in the size O.D. 0.055", I.D. 0.015". Accordingly, an order was placed for this tubing at a cost of $31.98 per 100 linear feet. One point of interest is the fact that there is a delay of six months in delivery.

PROPERTIES OF STAINLESS STEEL

BETA ABSORPTION

The range of 0.97 Mev. betas in Al (Z = 13) is 392 gm/cm^2 and in Au (Z = 79) about 80-100 gm/cm^2 greater. With gold tubing 0.020 cm thick, the betas penetrate the shield to some extent. Since the elements in the stainless steel are fairly close to Al, the gm/cm^2 required to stop the gold betas should approximate that for Al. This is indicated by a comparison of the elec-

tron density.

TABLE VI

COMPARISON OF ELECTRON DENSITIES

Element	Z	A*	Z/A	Z/A Relative to Al
Al	13	27	0.482	1.0
Fe	26	56	0.464	0.964
Cr	24	52	0.462	0.958
Ni	28	58	0.483	1.0
Au	79	197	0.401	0.831

* Number of most abundant isotope.

The gold shield in use totals 386 mg/cm^2. Using this in stainless steel should, therefore, stop all but a small percentage of the most energetic beta particles. With this value the tube thickness required is 0.050 cm or 0.020". The lesser energy betas will be completely shielded out by this thickness.

TUBING SIZE

Under existing plans, it is expected that 7 mil wire will be the largest used. With a 0.012" lumen as a minimum, the outer diameter would be 0.052". Converted to centimeters, these dimensions are I.D. 0.0304 cm, O.D. 0.1320 cm. It is believed the lumen will govern the final size since stainless steel is difficult to work. Using the above values gives 394 mg/cm^2 as a final shield thickness which should practically eliminate beta leakage except at the ends of the sources.

TUBING STRENGTH

Using the estimated yield strength and cross sec-

tion above, the tubing was analyzed as a column and as a simple beam. Even with the minimum size indicated and a 10 centimeter length, the tubing has considerable strength as a column. However, such a seed could be fairly easily bent. In the analysis, an extreme case was considered that would probably never be encountered in practice. The seed when inserted is acting as a short column. The main possibility for bending would occur if the seed were forced against a bone.

X-RAY PRODUCTION

Due to the hard beta emission from the gold wire and dense shield, X-rays will be produced. Both continuous and characteristic X-rays will be emitted. The first is due to the rapid deceleration of the charged particles in the wire and in the shield. The characteristic X-rays will be emitted by the various elements present with main emphasis on the Au, Fe, Cr, and Ni. The trace elements will be unimportant due to the very small percentage present.

In the braking action, continuous X-rays are emitted with all energies up to a maximum of 0.97 Mev. These continuous X-rays form the usual distribution curve with a mean energy emitted of about one third of the maximum. The characteristic X-rays are superimposed on the curve. The efficiency of X-ray production varies with Z and V. For the tubing shield,

$$\text{Efficiency (23,24)} = 1.4 \times 10^{-9}\ ZV$$
$$= 1.4 \times 10^{-9} \times 26 \times .97 \times 10^{6}$$
$$= 1.18\%$$

This assumes an average Z of 26 for the elements present. The efficiency in the wire itself is somewhat greater due to the higher Z number. However, the greatest part of the energy loss is in the stainless steel shield. Assuming all the energy loss is in the shield,

$$\text{X-ray energy} = 0.323 \times 0.0118$$
$$= 0.0038\ \text{Mev/Au-198 disintegration on the average.}$$

and $\dfrac{\text{Ratio X-ray energy}}{\gamma\text{ ray energy}}$ emitted $= \dfrac{.0038}{.411} = 0.92\%$

The lesser energy betas are neglected since they are in small amount. Thus, the X-rays are a very small percentage of the total energy emitted.

CHARACTERISTIC X-RAYS

As stated, characteristic X-rays will be emitted from all elements present. These have previously been given for gold by Colmery (5). The values for Fe, Cr, and Ni as taken from Compton and Allison (24, p. 784-788) are given below. Compton and Allison (24, p.787) list these values as "the more prominent lines" in the spectra.

TABLE VII

CHARACTERISTIC X-RAY SPECTRUM OF Fe

Line	Transition	λ A°	Energy (Mev.)
K	K-L	1.936012	0.00642
K	K-L	1.932076	0.00643
K	K-M	1.753013	0.00719
L	L-M	17.57	0.000708
L	L-M	17.23	0.000721
L	L-M	20.09	0.000618
L	L-M	19.76	0.000629

TABLE VIII

CHARACTERISTIC X-RAY SPECTRUM OF Cr

Line	Transition	λ A°	Energy (Mev.)
K	K-L	2.28891	0.00543
K	K-L	2.28503	0.00544
K	K-M	2.0806	0.00596
L	L-M	21.53	0.000577
L	L-M	21.19	0.000586
L	L-M	23.84	0.000521
L	L-M	23.28	0.000534

TABLE IX

CHARACTERISTIC X-RAY SPECTRUM OF Ni

Line	Transition	λ A°	Energy (Mev.)
K	K-L	1.65835	0.00750
K	K-L	1.65450	0.00751
K	K-M	1.47905	0.00840
K	K-N	1.48561	0.00837
L	L-M	14.53	0.000855
L	L-M	14.25	0.000871
L	L-M	16.66	0.000746
L	L-M	16.29	0.000763

Insepction of these values indicates a maximum energy of 8,400 volts. Thus, all of the characteristic X-rays will have very high absorption coefficients and be readily attenuated in the shield.

ABSORPTION OF GAMMA RAYS

Since the stainless steel will replace gold tubing as a shield, a comparison of the energy absorption in the two will be made. Only the 0.411 Mev. gamma will be considered since it is essentially 100% of the radiation. In the comparison, the radial thickness will be used. For short seeds and moderate distances, this provides a fair approximation for comparison. Actually for a point outside the seed, each differential element of the seed will have a different path length.

GOLD SHIELD

$$\frac{I}{I_0} = e^{-\mu r} = e^{-\mu_m \rho r} = e^{-0.218 \times 19.3 \times 0.020}$$

$$= 0.919$$

Where

$\mu_m = 0.218\ cm^2/gm$ = mass absorption coefficient for gold (16).

$\rho = 19.3\ gm/cm^2$ = density of gold.

$r = 0.020$ cm = radial tube thickness.

STEEL SHIELD

$$\frac{I}{I_0} = e^{-\mu r} = e^{-\mu_m \rho r} = e^{-0.091 \times 7.75 \times 0.0508}$$

$$= 0.965$$

Where

$\mu_m = 0.091\ cm^2/gm$ = mass absorption coefficient for Fe (16).

$\rho = 7.75\ gm/cm^3$ = density of stainless steel (assumed).

$r = 0.0508$ cm = radial tube thickness.

Thus, less of the gamma energy is absorbed in the steel

shield than in the gold shield. In the above computations, the μ_m(Fe) was used as an approximation. However, Cr and Ni have approximately the same value.

ELECTROMAGNETIC ENERGY ABSORPTION

Since the actual radiation from a seed is composed of many components, an analysis was made to determine the distribution of the energies emitted. Each will be absorbed to a different degree in the shield so that the percentage passing the shield will be different from that emitted. In the computations, the total absorption coefficient was used to compute the attenuation. Actually some of this attenuation is due to scattering and energy is returned to the field. However, this effect is somewhat indeterminant. Colmery (5) evaluated the scattering effect in tissue but that in the shield is uncertain. The scattering will result in degradation to lower energies with higher absorption coefficients. The main effect of such degradation is to restrict low energy effects to points close to the seed.

In these comparisons, the radial shield thickness was again used for the path length. In addition, the radius of the gold wire was included. The attenuation due to each part was computed separately since the gold and steel have different absorption coefficients. The absorption coefficient for Fe was used for the shield as an approximation. All emissions were assumed to be

random in direction. The results of the computations are tabulated on succeeding pages.

RECOIL ELECTRONS

The main gamma energy is the 0.411 Mev gamma from Au-198. This is partially attenuated by the shield. The photo-electric and Compton effects result in recoil electrons, some of which may reach the surface of the seed. A total of 7.2% of the energy of the 0.411 Mev gamma is lost in the wire and shield. The range of 0.411 Mev electrons is 0.119 gm/cm^2 from Feather's range equation (26). This converts to 0.0154 cm in the steel shield. Thus, a recoil electron at this distance from the surface could theoretically just reach the surface of the seed and those at shallower depths could pass out into the tissue. By taking a ratio of the areas of shield outside and inside this depth and considering the total energy absorbed, it was found that 2.9% of the gamma energy is changed to recoil electrons that could reach the tissue. However, the actual energy passing the shield from this source is reduced due to absorption of the recoil electrons and other causes. The actual energy should be much less than 1%.

TABLE X

STAINLESS STEEL SHIELD ENERGY ANALYSIS

Radiation (Mev)	Abundance per cent	Fraction Passing Shield	Relative Energy Emission	Origin
0.411 γ	99.67	0.928	1.0000	Au-198
0.158 γ	~ 0.13	0.665	0.0010	Au-199
0.208 γ	~ 0.07	0.817	0.0006	Au-199
~0.330 γ	1.18	0.909	0.0118	Au-198
0.67 γ	1.43	0.954	0.0147	Au-198
1.09 γ	0.33	0.963	0.0035	Au-198
0.97 β	98.24	Shielded out	- - -	Au-198
0.32 β	~ 1.00	Shielded out	- - -	Au-199
0.295 β	1.76	Shielded out	- - -	Au-198
Recoil electrons		- - -	< 1%	Au-198
Conversion electrons		Shielded out	- - -	Au-198

The relative energy emission for gamma rays expresses the fraction passing the shield for each 0.411 Mev gamma emitted. The actual energy emission would be the relative energy emission times the gamma energy.

Essentially the radiation consists of 0.411 Mev gamma rays. In computing a dosage diagram, the 0.411 Mev gammas were considered as the only emission to simplify the computations. The error due to this approximation is small, perhaps of the order of 2-3%.

IX. BIOLOGICAL EXPERIMENTS

GENERAL

Originally it was planned to use the gold seeds in vivo on larger animals. However, due to delay in the delivery of the gold tubing and the short time remaining, these experiments were cancelled. Instead, an in vitro experiment was projected to determine the cancerocidal dose for each of the four mouse tumors on hand. Briefly, tumors were to be excised, placed in suspension in saline, irradiated with various dosages and then injected into mice to determine the percentages of takes. Repetition with varying dosages and different sources would indicate comparative cancerocidal doses. It was desired to irradiate with X-rays, Au-198, Radium, and Co-60 sources to secure comparative data. This sequence could be accomplished providing the tumor could be kept viable for a suitable length of time.

In order to accomplish the projected experiment the following sequence was established:

1) Control experiments were necessary to determine the viability of each type of mouse tumor.

2) Computations were made to establish the size of sources and geometry necessary for irradiation and the attendant problems of measurement of dosage of radiation.

3) Upon completion of the first two items, had viability proven to be satisfactory, tumors would have

been excised, irradiated, and injected into healthy mice and the cancerocidal doses determined. As work progressed; it became apparent that viability was the controlling factor. Also, considerable time was required to accomplish the control experiments. Accordingly only the first two parts of the program were completed and the results are given here.

CONTROL EXPERIMENTS

GENERAL

In these experiments the following tumors and mice were used:

TABLE XI

MOUSE AND TUMOR STRAINS

Mice	Tumor
A	Lymphosarcoma
CFW	Sarcoma 37
C3H	Adenocarcinoma - C3HBA
ABC	Mammary Gland Carcinoma 15091a

Two types of experiments were run on each strain. In the first, the excised tumor was immediately ground and placed in suspension in sterile saline which was incubated at 37° C. Injections were made into healthy mice at successively later times to determine the viability. In the other type of experiment, the excised tumor was cut into large lumps. One of these was ground immediately and injected as a control. The others were kept in sterile saline at 37° C in lump form. At later times each was ground, suspended in saline, and injected into

healthy mice. Thus, there were eight sets of data to accumulate on the viability.

TECHNIQUE

During the experiments, materials and equipment available in the laboratory were used. Mainly these consisted of small scissors, forceps, hemostats, test tubes and flasks. BD Yale Tuberculin Syringes No 1YT with 1", 22 gauge hypodermic needles were used in the injections. All small equipment such as the syringes were boiled before use. The 0.85% sodium chloride, grinding tools, flasks and test tubes were autoclaved. Cotton sponges with 70% ethyl alcohol were used for swabs.

In the process, the tumor-bearing mouse was sacrificed using ethyl ether. The tumor was then excised and placed in the grinding tool. This was mounted on a flask that was connected to an aspirator. The tumor was mashed up with a rough glass rod and forced through a fine screen. Sterile saline was poured through the screen. The grinding produced a good suspension of fine particles. During the run, the saline was kept as close to 37° C as possible. Some difficulty was encountered in applying aseptic technique mainly due to inexperience. Mice were inoculated subcutaneously bilaterally. At first 0.1 cc was used per injection but this was later reduced to 0.05 cc. Three mice were

used for each period which gave six sites for possible takes. Mice were kept in one quart mason jars after inoculation, with food and water permanently at hand. They were examined daily for tumor growth and the jars serviced. Inoculated mice were retained for one month and then disposed of. Generally, if tumor growth were to occur it was observed in the first two weeks.

COMMENTS ON THE RESULTS

Originally, it was planned to irradiate a tumor suspension for 10 hours. In order to excise and handle the tumor during this time of irradiation without appreciable loss of viability other than that due to radiation, the tumor should remain viable _in vitro_ for 14-16 hours. This is a considerable time and none of the tests proved any such viable period. The following results were observed:

TABLE XII

VIABILITY OF MOUSE TUMORS

Tumor	Form	Maximum Observed Viability in hours
Lymphosarcoma	Suspension	1.5 *
Lymphosarcoma	Lump	$<$ 2.0
Sarcoma 37	Suspension	4.0 - *
Sarcoma 37	Lump	4.0 - *
C3HBA	Suspension	8.0
C3HBA	Lump	4.0 - *
15091a	Suspension	12.0 *
15091a	Lump	8.0 - *

* In these cases only partial growth was observed at the times given. In the others, growth was 6/6.

The 15091a and C3HBA apparently offer the best opportunity for extensive experiments. However, these are the most resistant tumors and would require large sources at close geometry for short-time irradiation. This poses problems in personnel hazards unless special precautions are taken in the irradiation procedure. Data from which Table XII was constructed are given in Appendix VI.

IRRADIATION TECHNIQUE

GENERAL

While carrying out the control experiments, calculations were made to establish the source size necessary for irradiation. It was desired to irradiate in a phantom approximating tissue. Several possibilities were considered for this phantom and included tempered masonite, lucite, and cheese, among others. The masonite was found to be reasonable in cost and probably the best possibility since it could be easily and accurately worked. The lucite is fairly expensive with a one cubic foot block costing about $80.00 - $90.00.

It was decided to use a central source in the block with test tubes of tumor lumps or suspension on a circle surrounding the source at a distance of 4 centimeters. The phantom would be made up and the positioning

holes accurately drilled. Small plastic test tubes, one centimeter or less in diameter, would be used to hold the tumor suspension. A test tube 0.75 cm in diameter would provide an approximately spherical volume at the bottom sufficient to inoculate three mice bilaterally. Thus, several samples could be irradiated at the same time and receive dosage according to the time of exposure. The phantom with a composition similar to that of tissue would give approximately the same scattering effects as tissue so that comparisons could be drawn about the effectiveness of sources. Dosage measurements would be made with the 100 r or 250 r chamber of the Victoreen Condenser r-Meter. These chambers, being very small, would give a fair dosage measurement. Since only very short distances were involved, the dose would not be very accurate as the field would not be uniform across the chamber. However, since comparative results were mainly desired, the method would be satisfactory.

SOURCE SIZE

The lymphosarcoma was chosen as the initial tumor to be used since it was the most sensitive in previous work (5). A killing dose was established as 800 $\pm$ 200 r *in vivo*. Since material *in vitro* would probably be more resistant, a range of 2500 r in 10 hours was planned. This could be fractionated as desired by removing parts of the tumor suspension at shorter times. Radium and

cobalt would have a constant activity for the irradiation time specified, whereas the gold activity would decrease. Thus, it was necessary to compute the approximate source size for the projected irradiation conditions.

Radium:

1 mc = 0.84 mrhm (with a 0.5 mm Pt shield)

Using a 4 centimeter irradiation distance and neglecting absorption in the block for the present:

$$\text{Millicuries required} = \frac{2500 \text{ r}}{10 \text{ hr} \times 0.84 \times 10^{-3} \times 25^2 \text{ r/hr/mc}}$$

$$= 477 \text{ mc}$$

With an average gamma energy of 1.2 Mev, the absorption coefficient in tissue is $\mu_m = 0.062 \text{ cm}^2/\text{gm}$ (16)

and $e^{-\mu_m \rho x} = 0.766$ = tissue attenuation factor

$$\therefore \text{Millicuries required} = \frac{477}{.766} = 621 \text{ mc}$$

Cobalt:

This has an average gamma energy of 1.2 Mev and "1 rd Co-60 = 0.0352 mrhm" (43) in air neglecting air absorption.

$\therefore$ 1 curie Co-60 = 1.30 roentgens per hour at one meter.

At 4 centimeters neglecting absorption:

r/hr = $1.30 \times 25^2 = 812.5$ for a one curie source

Using the same absorption factor as before:

$$\text{Millicuries required} = \frac{2500}{8125} \times \frac{10^3}{.766} = 402 \text{ mc}$$

Cobalt sources are readily available at Oak Ridge in wire form so that this source could be obtained without difficulty.

Gold:

As a source this presents more of a problem than the cobalt or radium. For one thing, the gold has a high absorption coefficient. This results in considerable self absorption. Existing wire could be used as a source by cutting it into short pieces and placing it in the bottom of a small test tube after irradiation. Or a gold sphere could be procured of sufficient size to give the source strength necessary after irradiation in the pile. As an experiment six feet of 7 mil wire was wrapped around a small glass rod in the laboratory. This gave a ball about 5 mm in diameter. This could be reduced in size if necessary. Probably a solid gold sphere of suitable size would be more appropriate. Sample calculations were made to determine the size necessary. However, the self absorption is the uncertain factor since the center of the sphere would not be as active as the surface and gammas emitted at the center would be attenuated to a greater extent. In order to estimate the amount required, computations were based on bare 7 mil wire after receipt from Oak Ridge.

Usable activity in 30 cm $\cong$ 30 x 3 mrhm

$\cong$ 56.2 r/hr @ 4 cm neglecting absorption.

The linear absorption coefficient for 0.411 Mev gammas in tissue is:

$$\mu = 0.111 \text{ cm}^{-1} \ (16)$$

$$\text{Absorption factor} = e^{-\mu x} = e^{-0.111 \times 4}$$

$$= .641 \text{ for a 4 centimeter distance.}$$

$\therefore$ Usable activity in

$$\text{30 cm of wire} \cong .641 \times 56.2$$

$$\cong 36 \text{ r/hr @ 4 cm}$$

In 10 hours, the activity will not change too much due to decay.

$$\therefore \text{Wire required} \cong \frac{2500}{36 \times 10} \times 30 \text{ cm}$$

$$\cong 6.8 \text{ feet of 7 mil diameter}$$

As stated this can be wrapped into a small ball or it could be cut into short lengths and put in the bottom of a test tube. In either case self absorption would be uncertain. Actually considerable leeway should be allowed on any source set up in the future. One other point is the fact that the above does not include any beta shield. This is not considered necessary since the betas have a very short range in tissue. With a gold source a longer radiation time would be very advantageous. However, this conflicts with the problem of tumor viability.

CONCLUSIONS

It is believed the method is feasible with some of

the longer lived tumors. However, short irradiation times would be necessary and consequently large sources would be required. These in turn would require extensive shielding and remote control devices. Measurement would also be a problem. Since tumor viability is the governing factor, some effort should be expended on other methods of keeping the tumor alive. Possibly a better oxygen supply, agitation or change to a better medium would be appropriate. Any of these types of experiment will require considerable effort, care, and time. The present work was unsuccessful in that no irradiation results were secured. However, the work was beneficial in that it provided sufficient background information for an extension in the future.

X. SUMMARY AND CONCLUSIONS

In the process of carrying on this research, the following tasks have been accomplished:

The literature has been searched to date for information on the use of Au-198 in solid form and its properties. No references have been found giving other than gold colloid applications. The latest decay scheme found is as given in the initial pages of this paper.

Absorption studies have been made using Al, Pt, Au and Pb absorbers and new tubing and wire sizes selected for use based on these data. These sizes have been used experimentally.

The calibration of seeds has been improved and has been supplemented by an electroscope calibration against standardized gold. The improved method consists of using an energy independent condenser for the measurement.

Four sizes of gold wire have been irradiated and their activities compared along with sections of radioactive gold tubing. It has been concluded from these comparisons that shielding in the thicker sections results in slightly decreased activity. Lowered specific activity also resulted in the smaller wire sizes but this is explainable by manufacturing tolerances.

Seeds have been cut along many sections of wire and their activities compared. It has been concluded that

the wire on hand is fairly uniform along its length, with no rapid changes in size.

An improved cutting technique has been developed using the original cutting device. The device has been calibrated and the new method used experimentally with good results. Seeds cut by the new method are accurately cut and are much more uniform than those cut by the old method. In addition, the method is quicker and results in less irradiation exposure to personnel.

Derivations of dosage integrals for linear sources have been included for points on and off the axis of a source. These integrals have been evaluated for 4, 5, and 6 mil wire. It has been determined that one dosage diagram will suffice for 4, 5, 6 and 7 mil wire if the same thickness of gold tubing beta-shield is used.

Solutions of the dosage problem have been found for single plane interstitial implants for areas up to 7 x 7 cms. These have been tabulated and rules established for the implantation corresponding to those used with radium sources.

Isodose lines about typical seeds have been determined by calculation and experiment. These two methods gave comparable results. The lines are restricted to an area close around the ends of a source so that care must be taken to cross sources when they are used in patterns.

One shipment of twelve radon seeds has been analyzed.

While no leakage was found, the seeds were found to vary greatly in strength and to have considerable beta-leakage through the side walls.

Calculations have been made to adapt stainless steel tubing as a beta-shield replacing the gold tubing. The necessary tubing size has been established and its properties and effect on the radiation field analyzed.

Studies have been made to establish the viability *in vitro* of the four mouse tumors presently in use. In addition, calculations were completed on the source size and geometry for irradiation *in vitro*. While the overall experiment was unsuccessful, the parts completed add to the general knowledge.

Thus, through this work, the application of radioactive gold wire to cancer therapy has been furthered. Using the above information and that established previously (5) in additional animal experiments should provide sufficient experience to begin treatment of some human cases. Much work remains to be done on complex arrangements before the method can be considered reasonably complete.

APPENDIX I

ABSORPTION STUDIES

GENERAL

The absorption studies were initiated to provide a basis for the selection of tubing thickness. These studies were carried out in the usual fashion by interposing various absorber thicknesses between source and counting tube and measuring the activity.

PREPARATION OF ABSORBERS

In the experiments, aluminum, platinum, gold and lead were used as absorbers. Gold and platinum absorbers were 1" diameter disks of varying thickness. Gold disks were 0.0005" and 0.005" thick. Platinum disks were 0.001" and 0.005" thick. Lead and aluminum absorbers were taken from a standard set manufactured by Tracerlab, Inc. These were supplemented by lead disks 0.005" and 0.008" thick.

The gold and platinum disks were individually marked. They were then weighed to 0.1 milligram and the mg/cm^2 computed for each disk. A table summarizing the weights of various combinations was made up to assist in obtaining a smooth set of data in the experiment. Weights in mg/cm^2 were tabulated by Tracerlab for the lead and aluminum absorbers. Weights in mg/cm^2 for the 0.005" and 0.008" lead disks were computed values.

PREPARATION OF SAMPLES

A drop of red gold colloid (Abbott Laboratories, North Chicago, Ill.) was used as a beta source in the experiment. Its original strength was not known. This source was mounted on a Zapon sheet covering an open cardboard sample box. The Zapon was 0.6 mg/cm^2 in thickness. After placing the drop on the Zapon, it was evaporated to dryness and then covered by a similar sheet. Since there was a thin film involved and essentially an air backing, self absorption and back scattering were reduced to a minimum. Preparation was very easy and required little time. Rubber gloves were worn as a protection against possible contamination of the hands. A total of two samples were prepared.

COLLECTION OF DATA

In conducting the experiments, the following equipment was used:

Autoscalars - Tracerlab. OSU 238137, 234689.

Sample Holder - Tracerlab, Model SC 10 A.

Tube - Nucleonics Corporation GM Tube 1WA, Serial 114, 2.3 mg/cm^2 window.

The sample holder was fitted with two trays and numerous slots for proper positioning of sample and absorber. The tube was mounted vertically in the device. Each sample was positioned vertically depending on its activity at the time of the run and then the absorber

tray was placed in the slot immediately above the sample. No shielding was used around the sample holder.

When set up, background readings were taken before and after the runs and averaged. These readings were fairly constant and generally amounted to a small percentage of the total activity. Also, a plateau was run using each scalar. Using OSU 238137, the tube was operated at 1250 V. Using the other scalar, 1270 V were applied. In addition, the room temperature, barometer, Zapon thickness, window thickness and air column lengths were recorded for each run. These were used to determine the corrections to be applied to the measured absorber thickness. During each run, readings of scaler time versus absorber thickness were recorded along with the clock time. Either two or three readings were taken for each point depending on the physical conditions. 4096 counts were used as a basis for most of the observations. This was reduced to 2048 counts only when the time became excessive. The activities used were many times background so the results were still valid.

ANALYSIS OF RESULTS

Data taken were analyzed by solving for counts per second versus absorber thickness in mg/cm^2. These were corrected for background and decay. The absorber thickness was computed from the data previously mentioned. Points were plotted on semilog paper with activity as

an ordinate and mg/cm^2 as abscissa. The maximum range was determined visually. Results were as reported in the section on Seed Preparation. A sample absorption plot using gold absorbers is included on succeeding pages.

BETA ABSORPTION USING GOLD ABSORBERS AND A GOLD COLLOID SOURCE

In this run the gold colloid was used as a source. It was mounted in the lowest slot of the sample holder and the gold absorbers were placed immediately above it. The air column length between source and tube was 8 cm. Readings were taken as indicated. The temperature during the run was 25° C and the barometric pressure was 29.53" Hg. The autoscalar used was OSU 234689 and the geiger tube was operated at 1270 volts. Three observations were made on each thickness. Background was 1.2 counts/second. All data was taken on 11/20/51.

TABLE XIII

BETA ABSORPTION DATA USING GOLD ABSORBERS

Time	C Counts	t Scalar Sec	c/t	Bk.	c^{1}/t	* Decay Corr.	c^{11}/t	Au mg/cm^2
1005	4096	83.6	48.9	1.2	47.7	1.0	47.7	1205.3
1010		79.0	51.8		50.6	1.0	50.6	1103.2
1015		78.5	52.2		51.0	1.001	51.0	1004.5
1020		79.2	51.6		50.4	1.001	50.4	860.2
1025		74.4	55.0		53.8	1.002	53.8	758.2
1030		76.5	53.5		52.3	1.003	52.4	706.0
1035		73.3	55.8		54.6	1.005	54.8	654.1
1042		72.0	56.8		55.6	1.007	56.0	607.3
1045		68.9	59.4		58.2	1.008	58.6	560.6
1050		67.9	60.2		59.0	1.009	59.5	505.2
1055		69.6	58.8		57.6	1.010	58.2	454.1
1100		69.5	58.9		57.7	1.0104	58.3	427.0
1105		68.5	59.8		58.6	1.0107	59.2	402.2
1130		68.3	59.9		58.7	1.0152	59.6	379.2
1140		68.1	60.1		58.9	1.0170	59.8	355.5
1142		68.4	59.8		58.6	1.0170	59.6	332.2
1145		65.4	62.5		61.3	1.0180	62.4	308.8
1150		64.0	64.0		62.8	1.0189	63.9	281.2
1155		61.8	66.2		65.0	1.0198	66.2	253.4
1157		58.6	69.8		68.6	1.0200	70.0	200.8
1200		53.4	76.7		75.5	1.0206	77.0	173.7
1205		41.5	98.6		97.4	1.0216	99.5	148.9
1206		32.0	128.0		127.0	1.0216	130.0	125.8
1207		23.3	175.5		174.0	1.0220	178.0	102.1
1210		15.5	284.		283.	1.0234	289.	78.8
1210		10.6	387.		386.	1.0234	395.	55.4
1210		7.0	585.		584.	1.0234	598.	27.8

* Decay corrections are as reported by Colmery (5).

Corrections:

Tube window thickness = 2.3

Air column thickness = 9.6

Zapon thickness = 0.6

Total = 12.5 mg/cm^2

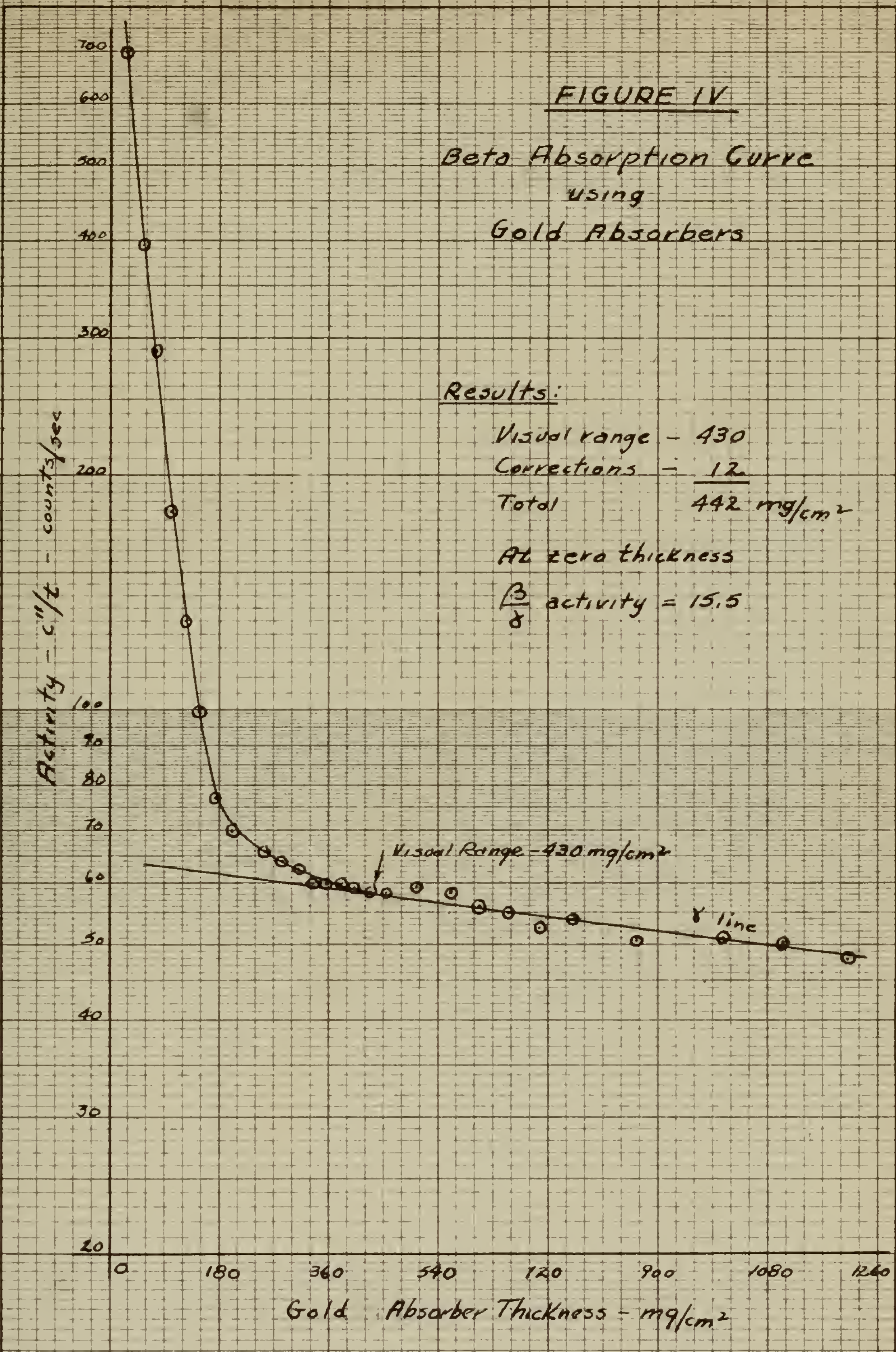


FIGURE IV
Beta Absorption Curve using Gold Absorbers
Results:
Visual range - 430
Corrections - 12
Total 442 mg/cm²
At zero thickness
β/γ activity = 15.5
Visual Range - 430 mg/cm²
γ line
Activity - c''/t - counts/sec
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
0
180
360
540
720
900
1080
1260
Gold Absorber Thickness - mg/cm²

BETA ABSORPTION STUDY USING

ALUMINUM ABSORBERS AND A RADIOACTIVE GOLD SEED

As stated in the text, after receipt of the radioactive gold wire, one seed was analyzed for beta emission through the side walls. Paraffin was used to eliminate beta particles at the ends where the gold shield was thin. Thus, only beta particles through the sides were measured.

The procedure was exactly as before. A Tracerlab Autoscalar, OSU 218019, was used in the run with Tracerlab Geiger Tube, Serial 4 D 73. The tube had a 1.5 mg/cm^2 window and was operated at 1500 volts. The Tracerlab set of aluminum absorbers was used. No corrections were made in this run for air column and window thickness. The gold seed used as a source was one centimeter long and was cut from radioactive wire received in the second shipment, 4/1/52. All data was taken on 4/15/52. Three observations were made for each absorber thickness. Background was 0.9 counts/second.

TABLE XIV

BETA ABSORPTION DATA USING ALUMINUM ABSORBERS

Time	C Counts	t Scaler Sec	c/t	Bk.	c^{1}/t	Decay corr.	c^{11}/t	Al mg/cm^2
1046	4096	40.2	101.9	0.9	101.0	1.00	101.	1320.
1048		38.5	106.4		105.5	1.00	106.	1113.
1050		37.9	108.0		107.1	1.00	107.	896.
1053		37.4	109.4		108.5	1.001	109.	642.
1056		37.0	110.7		109.8	1.001	110.	490.
1058		35.8	114.4		113.5	1.001	114.	343.
1100		35.7	114.7		113.8	1.001	114.	273.
1102		36.0	113.7		112.8	1.001	113.	217.
1105		37.7	108.7		107.8	1.002	108.	188.
1107		37.2	110.1		109.2	1.002	109.	164.8
1110		35.7	114.7		113.8	1.003	114.	130.4
1114		36.0	113.7		112.8	1.005	113.	122.1
1116		36.5	112.3		111.4	1.005	112.	117.9
1117		36.0	113.7		112.8	1.005	113.	107.3
1120		37.1	110.4		109.5	1.006	110.	96.1
1123		36.0	113.7		112.8	1.006	114.	85.5
1125		35.7	114.7		113.8	1.008	115.	80.1
1127		35.8	114.4		113.5	1.008	114.	72.3
1130		35.1	116.6		115.7	1.009	117.	68.1
1132		34.4	119.1		118.2	1.009	119.	57.5
1135		32.9	124.4		123.5	1.010	125.	42.8
1136		30.1	136.1		135.2	1.010	137.	28.0
1138		29.1	140.6		139.7	1.010	141.	23.1
1139		27.9	146.8		145.9	1.0104	147.	14.8
1142		27.0	151.7		150.8	1.0104	152.	10.6
1143		26.4	155.1		154.2	1.0107	156.	7.9
1145		26.0	157.5		156.6	1.0107	158.	5.0
1147		25.4	161.3		160.4	1.0107	162.	2.57
1148		25.0	163.8		162.9	1.011	165.	1.67
1150		24.5	167.2		166.3	1.0117	168.	0.

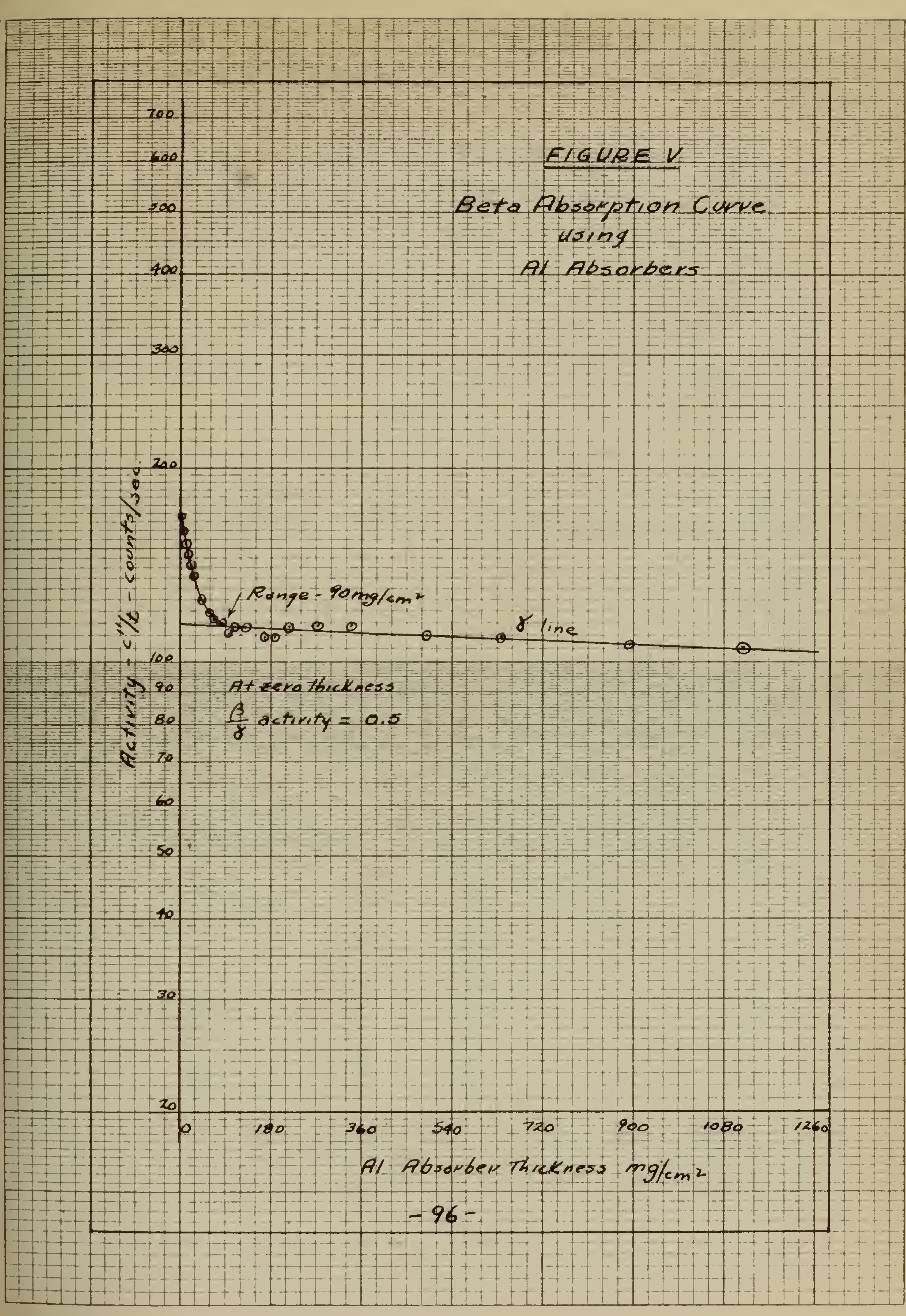


FIGURE V
Beta Absorption Curve
using
Al Absorbers
Range - 90mg/cm²
γ line
At zero thickness
β/γ activity = 0.5
Activity - c/t - counts/sec.
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
0
180
360
540
720
900
1080
1260
Al Absorber Thickness mg/cm²

APPENDIX II

SEED PREPARATION AND CHARACTERISTICS

PREPARATION OF IRRADIATION SAMPLES

A total of four gold samples were prepared and forwarded to Oak Ridge for analysis. These were prepared by the procedure given in the text, p. 28. Characteristics of the samples were as given below:

TABLE XV

IRRADIATION SAMPLE DATA

Sample No.	Wire Size Mils	Tubing Size	Wire mg	Tubing mg	Total mg
1	7	- - -	152.6	- - -	152.6
2	4,5,6,7	I.D. 0.005" O.D. 0.021"	92.0	94.9	186.9
3	4,5,6,7	I.D. 0.005" O.D. 0.021"	93.9	83.5	177.4
4	4,5,6,7	I.D. 0.030 cm O.D. 0.070 cm	92.7	44.4	137.1

TABLE XV - Cont'd

Sample No.	Shipping Container	Rec'd	Assumed Time out of Pile	Irradiation Time - Days	Activity*
1	Non-Returnable	1600 2/19	1000 2/18	7	39
2	Returnable	1610 4/1	1000 3/31	7	30
3	Non-Returnable	1530 4/8	1000 4/7	7	48
4	Non-Returnable	1115 4/15	1000 4/14	7	48

* This was the activity at the top of the shipping container in mr/hr projected back to the time of

removal from the nuclear reactor.

It is to be noted that about 1 1/4 days of shipping and handling time is involved before receipt of a sample at the laboratory. This results in decay to about 72 per cent of the initial activity. It is to be noted that the larger sample required a heavy returnable container involving a greater expense. The shipping charges for this container were $6.33.

CALIBRATION DATA

As stated in the text a large ringstand was used for positioning the source with respect to the meter. Two meters were used in the calibrations. These were the Victoreen Condenser r-Meter, Model 70, Serial #1618, OSU 164516, with 250 mr chamber and a Quartz Fiber Electroscope, Model 2, Serial #124, OSU 182712. The Model 70 meter was manufactured by the Victoreen Instrument Co., of Cleveland, Ohio; the electroscope by the F. C. Henson Co., of Pasadena, California.

TABLE XVI

RADIUM CALIBRATION DATA

These data were obtained with the Victoreen Condenser r-Meter with 250 mr chamber and a 9.54 mg Radium source shielded with 0.5 mm of platinum.

Date	Time	Run	Elapsed Time (min.)	Distance cm	Meter mr
1/23	2030	1	30	22.5	78.0
1/31	2000	2	60	34.5	69.0
2/12	2000	3	30	36.3	30.5
2/12	2030	4	30	36.3	31.5
2/12	2115	5	30	36.3	31.0
2/13	1915	6	31	34.2	36.0
2/13	2000	7	33	34.2	38.5
2/13	2045	8	60	34.2	69.0
2/14	1930	9	63	34.1	73.5
2/14	2030	10	30	34.1	35.0
2/14	2120	11	30	25.4	61.5
2/18	1930	12	30	25.4	63.0
2/18	2015	13	60	25.4	124.0
2/18	2115	14	30	25.4	62.5

TABLE XVI - Cont'd.

Run	Meter mr	T^oc	Bar. " Hg	Corr.	True mr	Calc. mr	% Diff.
1	78.0	26.0	29.33	1.035	80.6	79.7	1.1
2	69.0	25.5	29.42	1.029	70.9	67.4	5.2
3	30.5	26.5	29.12	1.044	31.8	30.4	4.6
4	31.5	26.5	29.12	1.044	32.9	30.4	8.2
5	31.0	26.5	29.12	1.044	32.4	30.4	6.5
6	36.0	24.5	29.15	1.035	37.2	35.5	4.8
7	38.5	24.0	29.15	1.035	39.7	37.8	5.0
8	69.0	24.0	29.15	1.035	71.2	68.6	3.8
9	73.5	23.0	29.21	1.028	75.5	72.4	4.3
10	35.0	23.0	29.21	1.028	35.8	34.4	3.9
11	61.5	23.0	29.21	1.028	63.2	62.2	1.7
12	63.0	22.0	29.27	1.022	64.3	62.2	3.4
13	124.0	22.0	29.27	1.022	126.7	124.3	1.9
14	62.5	22.0	29.27	1.022	63.9	62.2	2.7

Since the last observations gave the closest values, the distance of 25.4 centimeters was retained and the equipment was kept permanently mounted at this distance.

TABLE XVII

GOLD CALIBRATION DATA

These data were obtained with the Victoreen Condenser r-Meter and 250 mr chamber and the standard calibration

ringstand. The sample was positioned 72.5 centimeters above the base and the chamber 47.1 centimeters above the base. This gave a distance of 25.4 centimeters between source and chamber. All seeds were constructed of 7 mil wire and I.D. 0.070 cm, O.D. 0.030 cm. gold tubing.

Date	Time	Shipment No.	Source length (cm)	Run	Elapsed Time (min)	Meter mr
2/19	2030	1	2	1	30	38
2/19	2100	1	2	2	31	38
2/19	2200	1	2	3	60	72
4/2	0950	2	2	4	60	69.
4/3	0900	2	4	5	60	104.5
4/3	1000	2	4	6	60	102
4/10	1600	3	4	7	60	109
4/10	1700	3	4	8	60	111
4/15	1320	4	4	9	30	76
4/15	1400	4	4	10	60	150

TABLE XVII - Cont'd

Run	Meter mr	T^oC	Bar. " Hg	Corr.	True mr
1	38	24	29.17	1.033	39.3
2	38	24	29.17	1.033	39.3
3	72	24	29.17	1.033	74.5
4	69	23	28.96	1.038	71.6
5	104.5	31	29.01	1.068	111.7
6	102	31	29.01	1.068	109.0
7	109	22	29.31	1.020	111.2
8	111	20	29.31	1.014	112.5
9	76	21.5	29.00	1.030	78.3
10	150	21	29.00	1.028	154.3

TABLE XVIII

ACTIVITY OF GOLD SHIPMENTS

Using the calibration data of Table XVII, the following activities were computed for 7 mil wire in

I.D. 0.030 cm, O. D. 0.070 cm. gold tubing.

Shipment	Activity mrhm/cm	Activity mrhm/mg	Time	Date
1	3.50	0.731	1000	2/18/52
2	3.88	0.811	1000	3/31/52
3	3.72	0.777	1000	4/7/52
4	3.37	0.704	1000	4/14/52

THE CORRECTION FACTOR FOR

CUTTING SEEDS AT THE MICROMETER END

In order to cut seeds accurately at the micrometer end, it was necessary to establish the cutting correction. Accordingly, 50 seeds were cut from non-radioactive gold tubing of I.D. 0.030 cm., O.D. 0.070 cm. Five seeds were cut for each micrometer setting. Ten steps were used with the micrometer being set initially at zero and then changed by 0.25 centimeter increments. All seeds were weighed to 0.1 mg. The data taken were analyzed and a plot made of seed length versus micrometer setting. This was extrapolated to zero to determine the correction. This indicated that a micrometer setting of zero would result in a 0.15 centimeter seed. Thus, the correction factor for cutting was (-) 0.15 cm. This must be added to all micrometer settings.

TABLE XIX

SEED CUTTING DATA, MICROMETER END

Micrometer Setting (cm)	Wt. of Seed mg	Aver. mg	Length cm
0.25	21.1	20.6	0.38
	21.3		
	20.6		

Micrometer Setting (cm)	Wt. of Seed mg	Aver. mg	Length cm
0.25	19.5	20.6	0.38
	20.3		
0.50	33.5	34.1	0.63
	34.0		
	33.7		
	34.5		
	34.7		
0.75	48.5	49.1	0.91
	48.1		
	50.5		
	48.6		
	49.6		
1.00	62.7	62.2	1.15
	61.3		
	62.6		
	61.9		
	62.6		
1.25	75.4	76.0	1.41
	76.4		
	76.0		
	76.3		
	75.8		
1.50	91.4	90.2	1.67
	91.2		
	91.8		
	88.6		
	88.2		
1.75	102.1	102.1	1.89
	101.8		
	102.5		
	102.2		
	101.8		
2.00	115.7	115.9	2.16
	115.7		
	115.5		
	117.0		
	115.5		
2.25	129.8	129.6	2.40
	130.0		
	129.1		
	129.7		
	129.2		
2.50	142.2	142.3	2.64
	143.1		
	142.5		
	142.1		
	141.8		

These data are plotted on the succeeding page. Individual weights were included to indicate the small size differences among seeds cut by this method.

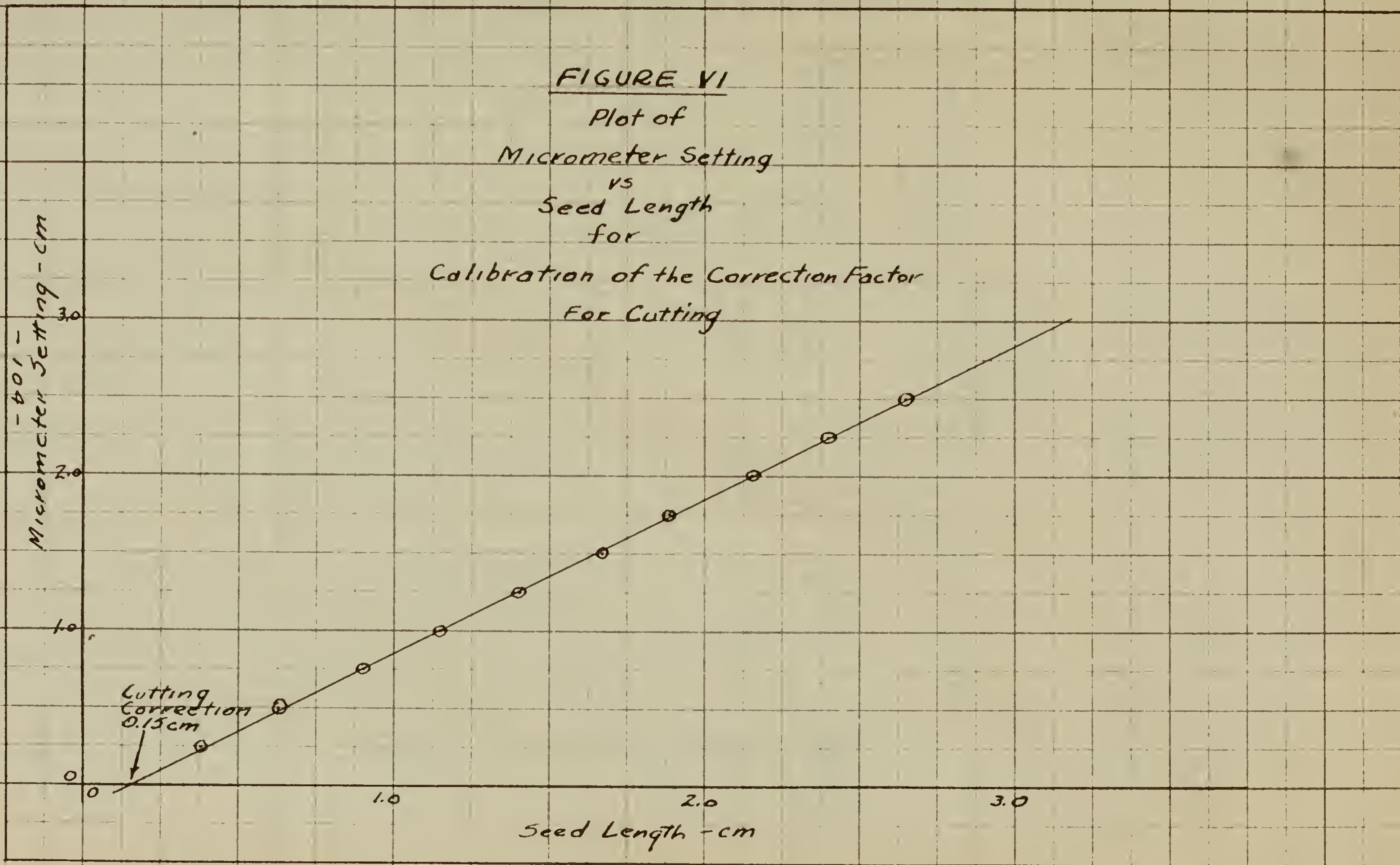


FIGURE VI
Plot of
Micrometer Setting
vs
Seed Length
for
Calibration of the Correction Factor
For Cutting

COMPARISON OF ACTIVITIES OF DIFFERENT WIRE AND TUBING SIZES IN DIFFERENT SHIPMENTS

Using the second, third, and fourth shipments, comparative data were taken to see if the same unit activity would be generated in the gold of a given dimension. These data are summarized in the following tables.

TABLE XX

SECOND SHIPMENT
COMPARATIVE ACTIVITY DATA FOR WIRE & TUBING
QUARTZ FIBER ELECTROSCOPE

Seed Size cm	No. of Samples		Wire Dia.	Active Wt. mg	Average Activity c/s	Activity mg	Relative Act/mg
1	3		7 mil	4.78	15.2	3.55	
2	2		7 mil	9.56	34.4	3.59	1.0
Tubing	1	I.D.	0.005"	56.2	143.0	2.55	
		O.D.	0.021"				
Tubing	1	I.D.	0.005"	38.7	101.7	2.62	0.72
		O.D.	0.021"				

The above data were taken using the standard calibration ringstand and the Quartz Fiber electroscope. A 412 mg/cm^2 Al shield was interposed to eliminate all beta radiation and allow the gamma activity to be compared. Since the active gold tubing had no gold shield surrounding it as did the gold wire, its observed activity was reduced by the absorption in an equal tubing thickness. Thus, the relative activities of the tubing and wire became comparable.

TABLE XXI

SECOND SHIPMENT
COMPARATIVE ACTIVITY DATA, GEIGER COUNTER

Seed Size cm	No. of Samples	Wire Dia.	Active Wt. mg	Average Activity c/s	Activity mg	Relative Act/mg
1	3	7 mil	4.78	173.6	36.3	1.00
1	5	5 mil	2.44	73.4	30.1	0.83
1	6	4 mil	1.56	58.1	37.3	1.03

The above table is a summary of data taken using Tracerlab Autoscalar OSU 238127 and Tracerlab Geiger Tube, TGC 2, Serial 4D73. Seeds were reproducibly positioned with respect to the tube by means of the standard calibration ringstand. The tube was operated at 1500 V. Readings were taken using 4096 counts. The computed activity was corrected for background and decay to bring the data to a comparative level.

TABLE XXII

THIRD SHIPMENT
COMPARATIVE ACTIVITY DATA FOR WIRE AND TUBING
GEIGER COUNTER

Seed Size cm	No. of Samples	Wire Dia.	Active Wt. mg	Average Activity c/s	Activity mg	Relative Act/mg
2.25	2	7 mil	10.73	48.6	4.53	1.0
Tubing	1	I.D. 0.005" O.D. 0.021"	47.1	163.2*	3.47	
Tubing	1	I.D. 0.005" O.D. 0.021"	36.4	128.8*	3.54	0.77

* These readings were corrected to account for the absorption in the gold tubing surrounding the gold wire.

TABLE XXIII

THIRD SHIPMENT
COMPARATIVE ACTIVITY DATA, GEIGER COUNTER

Seed Size cm	No. of Samples	Wire Dia.	Active Wt. mg	Average Activity c/s	Activity mg	Relative Act/mg
2.23	1	7 mil	10.66	159.6	15.0	
2.25	2	7 mil	10.73	155.3	14.5	1.0
1	7	6 mil	3.52	47.4	13.5	0.91
1	5	5 mil	2.44	27.7	11.4	0.78
1	7	4 mil	1.56	21.2	13.6	0.92

In Tables XXII and XXIII are summarized the data taken using the Tracerlab Autoscalar, OSU 218019, and Tracerlab Geiger Tube, Serial 4D73. Seeds were reproducibly positioned with respect to the tube by means of the calibration ringstand. The tube was operated at 1500 V. Readings were taken using 4096 counts. A 412 mg/cm^2 Al shield was interposed to eliminate all beta activity. The computed activity was corrected for background and decay to bring the data to a comparative level.

TABLE XXIV

FOURTH SHIPMENT
COMPARATIVE ACTIVITY DATA FOR WIRE AND TUBING

Seed Size cm	No. of Samples	Wire Dia.	Active Wt. mg	Average Activity c/s	Activity mg	Relative Act/mg
1	2	7 mil	4.78	76.0	15.9	
2	2	7 mil	9.56	151.8	15.9	1.0
1	7	6 mil	3.52	52.3	14.8	0.93
1	7	5 mil	2.44	29.8	12.2	0.77
1	7	4 mil	1.56	22.7	14.6	0.92
Tubing	1	I.D. 0.030cm O.D. 0.070cm	44.4	579.0	13.0*	0.75

*This activity was corrected to account for the absorption in the gold tubing surrounding the gold wire.

In Table XXIV are summarized the data taken in the same manner as described for Table XXIII.

SEED STATISTICS

The data taken to compare the activities of the different wire sizes was also used to evaluate the reproducibility of the cutting method. The results have been summarized in Table IV. The computations were based on small sample theory taken from Hoel (19). Since the computations were repetitious, only one example will be included here.

As given by Hoel (19, p.128).

$$\sigma^2 = \sum_i \frac{(x_i - \bar{x})^2}{(n-1)}$$

where σ is the standard deviation

x is the value of the observation

$\bar{x}$ is the mean value

n is the number of observations

This is the relation used below.

TABLE XXV

SAMPLE VARIATION COMPUTATION

Wire mils	Seed cm	x = c/s Activity	$\bar{x}$ Mean	$(x-\bar{x})^2$	$\frac{\sum(x-\bar{x})^2}{n-1}$	σ cm
6	1	51.5	52.0	0.25	0.63	0.015
6	1	52.0		0.00		
6	1	52.2		0.04		
6	1	52.7		0.49		
6	1	51.3		0.49		
6	1	51.1		0.81		
6	1	53.3		1.69		

The above data were taken on seeds in the fourth shipment. The σ was converted from c/s to centimeters for comparative purposes.

ELECTROSCOPE CALIBRATION

The standard calibration stand was used with the sample ring 72.5 centimeters above the base. The Quartz Fiber Electroscope, OSU 182712, was aligned beneath the sample on the base of the ringstand. Its position was marked so that it could be reproducibly positioned at any time. Using calibrated 7 mil seeds from the second, third, and fourth shipments, data were taken and a calibration curve drawn. Using the electroscope, a seed may be calibrated in just a few minutes. Therefore, the method, but not the accuracy, is better than when the Victoreen Condenser r-Meter is used. The accuracy of the electroscope calibration is dependent on the other method since it was used for the original seed calibration.

TABLE XXVI

ELECTROSCOPE CALIBRATION DATA

Seed cm	Activity Divisions x 10^2 / sec.	mrhm	Shipment No.	Date
2	15.1	0.93	2	4/8
4	29.8	1.87	2	4/8
2	95.4	5.83	3	4/8
2	95.7	5.81	3	4/8
1	48.9	2.89	3	4/8
1	49.7	2.89	3	4/8
4	98.4	6.00	3	4/11
2	48.9	3.00	3	4/11
2	50.5	3.00	3	4/11
1	25.5	1.49	3	4/11
1	24.5	1.49	3	4/11
6	67.0	4.16	3	4/14
4	44.8	2.78	3	4/14
2	22.2	1.39	3	4/14
1	11.3	0.69	3	4/14
2	76.1	4.95	4	4/14
1	39.0	2.47	4	4/15
1	39.6	2.47	4	4/15
3	94.9	6.16	4	4/16
2	63.7	4.11	4	4/16
1	31.0	2.05	4	4/16
1	31.6	2.05	4	4/16

These calibration data are plotted on the following page.

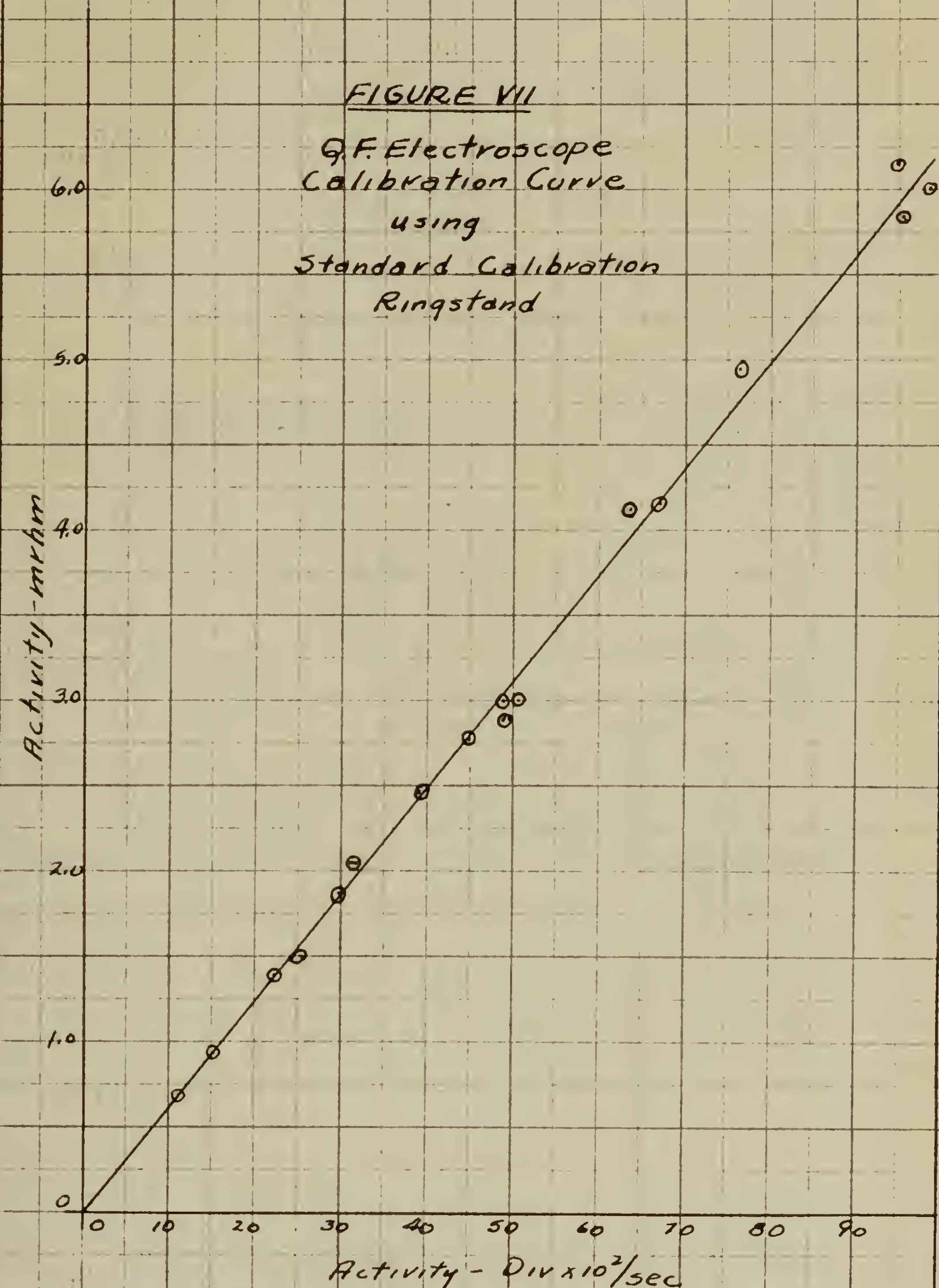


FIGURE VII
Q.F. Electroscope
Calibration Curve
using
Standard Calibration
Ringstand
6.0
5.0
4.0
3.0
2.0
1.0
0
Activity - mrhm
0
10
20
30
40
50
60
70
80
90
Activity - Div x 10²/sec

APPENDIX III

DERIVATION AND SOLUTION OF THE DOSAGE

EQUATIONS FOR A LINEAR SOURCE

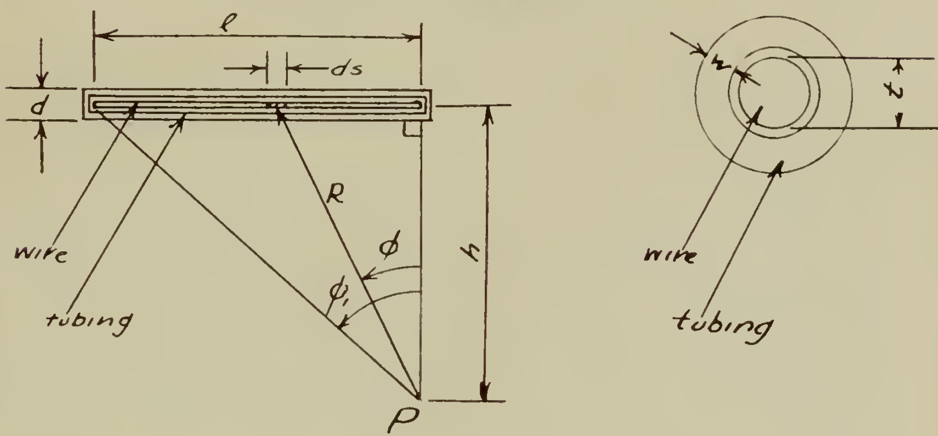
I. Points off the axis.

In the succeeding derivation, the following physical arrangement will be used:

FIGURE VIII

PHYSICAL ARRANGEMENTS FOR DOSAGE CALCULATIONS

POINTS OFF THE AXIS



In this derivation, the point P is fixed at a distance h on a perpendicular line through the end of the active gold. The same notation is used as before (5). The dosage diagram will be derived for a unit linear strength of one mrhm/cm. Multiples thereof will therefore cause a proportionate change in total dose.

Let k = the dose rate in r/hr/cm at 1 cm from an Au-198 source, shielded by (w + t/2) cm of gold, with a net seed strength of 1 mrhm/cm.

laboratory using short seeds approximating a point source.

Neglecting absorption but including the inverse square law.

Dose rate at P = $\int_0^{\ell} \frac{k\,ds}{R^2}$ r/hr

but $R\,d\phi$ = $ds \cos\phi$

ds = $R\sec\phi\, d\phi$

Therefore:

Dose Rate at P = $\int_0^{\phi_1} \frac{k}{R} \sec\phi\, d\phi$

Now there will be absorption in both the gold and tissue traversed as follows:

Gold absorption factor = $e^{-\mu_{\ell g}(w+\frac{t}{2})\sec\phi}$

Tissue absorption factor = $e^{-\mu_{\ell t}(h-\frac{d}{2})\sec\phi}$

Where $\mu_{\ell g}$ and $\mu_{\ell t}$ are the linear absorption and coefficients for gold and tissue respectively.

$\therefore$ Dose Rate at P = $\int_0^{\phi_1} \frac{k}{R} e^{-\mu_{\ell g}(w+\frac{t}{2})\sec\phi} \cdot e^{-\mu_{\ell t}(h-\frac{d}{2})\sec\phi} \sec\phi\, d\phi$

But k included an absorption factor for (w+t/2) cm of gold.

Also R = h $\sec\phi$

$\therefore$ Dose Rate at P = $\int_0^{\phi_1} \frac{k}{h} e^{-[\mu_{\ell g}(w+\frac{t}{2})(\sec\phi-1)+\mu_{\ell t}(h-\frac{d}{2})\sec\phi]} d\phi$

$= \int_0^{\phi_1} \frac{k}{h} e^{-g} d\phi$

$= \int_0^{\phi_1} f(\phi)\, d\phi$

where $f(\phi)$ = $\frac{k}{h} e^{-g}$

This integral may be solved numerically by selecting h and then finding $f(\phi)$ for various values of ϕ.

Using these data $f(\phi)$ is plotted versus ϕ and the angle necessary to give a particular dose rate is computed from the graph. $f(\phi)$ is in terms of r/hr/degree. In order to get the lifetime r, the dose rate must be multiplied by the mean life, 93.5 hours. This will be absorbed in the constant C.

Factors used in the evaluation are as follows:

$$g = \left[\mu_{rg}(w + t/2)(\sec\phi - 1) + \mu_{et}(h - d/2)\sec\phi\right]$$

$$C = 93.5\ (k/h)\ \frac{(2\pi)}{(360)} = \frac{16.31}{h} \quad \text{lifetime r/degree}$$

$\frac{2\pi}{360}$ converts from radians to degrees.

k = 10 r/hr at 1 cm from a 1 mrhm/cm source shielded as given.

μ_{rg} = 4.21 cm^{-1} (16)

μ_{et} = 0.111 cm^{-1} (16)

t_6 = 0.006" = 0.01524 cm

t_5 = 0.005" = 0.01270 cm

t_4 = 0.004" = 0.01016 cm

w = 0.020 cm

d = 0.070 cm

Steps in the solution:

1. Assume h and compute C
2. Compute g for each ϕ in 5° steps.
3. Compute $f(\phi) = Ce^{-g}$ = lifetime r/degree.
4. Plot $f(\phi)$ versus ϕ.
5. Graphically integrate to get lifetime r versus ϕ.

6. Repeat for several values of h.

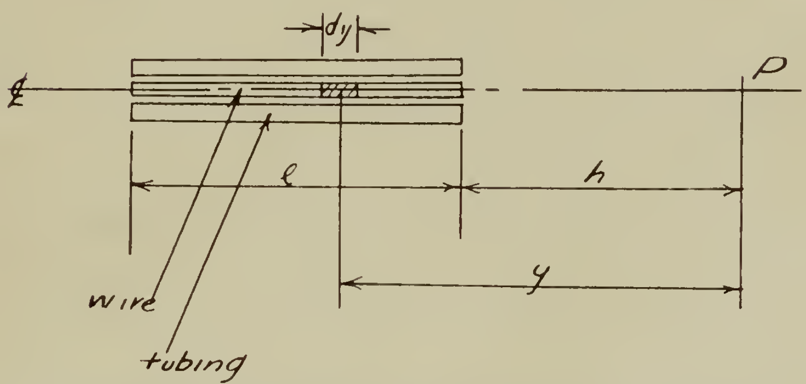
7. Plot data to form the dosage diagram.

II. Points on the Axis.

FIGURE IX

PHYSICAL ARRANGEMENT FOR DOSAGE CALCULATIONS

POINTS ON THE AXIS



It is desired to determine the dose at point P given by a radioactive seed of activity 1 mrhm/cm. In this derivation, the thickness of the shield at the end of the wire is assumed to be zero. Also, the effect of scattering off the tubing walls is neglected and only the direct radiation is considered.

Let k = dose rate in r/hr/cm at 1 cm from a seed of 1 mrhm/cm. The shielding as before is $(w + t/2)$ cm of gold.

Dose rate at P $= \int_{h}^{l+h} \frac{k\,dy}{y^2}$ neglecting absorption.

Corrections:

1) Gold absorption correction $= e^{-\mu_g (y-h-w-t/2)}$

2) Tissue absorption correction $= e^{-\mu_{et}(h)}$

Where μ_{eg}, μ_{et}, w, and t/2 are the same as previously used and h is a selected distance.

$\therefore$ Dose rate at P $= \int_h^{\ell+h} \frac{k}{y^2} e^{-\mu_{eg}(y-h)} \cdot e^{\mu_{eg}(w+\frac{t}{2})} \cdot e^{-\mu_{et} h} \, dy$

or Dose rate at P $= k e^{\mu_{eg}(w+\frac{t}{2})} \cdot e^{(\mu_{eg}-\mu_{et})h} \int_h^{\ell+h} \frac{e^{-\mu_{eg} y}}{y^2} \, dy$

This integrates into a series that may be cut off if $\mu_{eg} y \ll 1$. However, the values used are > 1 and therefore, the series diverges. The integral may be evaluated numerically using the same type of procedure as before. To find the lifetime dose at P the rate may be multiplied by the 93.5 hour mean life.

Lifetime Dose at P $= 93.5 k e^{\mu_{eg}(w+\frac{t}{2})} \int_h^{\ell+h} \frac{e^{[(\mu_{eg}-\mu_{et})h-\mu_{eg} y]}}{y^2} \, dy$

Data used in the solution:

k = 10 r/hr/cm at 1 cm.

93.5 = mean life in hours.

$\mu_{eg} = 4.21$ cm^{-1} (16)

$\mu_{et} = 0.111$ cm^{-1} (16)

w = 0.020 cm

t_6 = 0.01524 cm

t_5 = 0.01270 cm

t_4 = 0.01016 cm

The values of μ used in the computation of cases I and II were derived from curves furnished by Morgan (16) giving the mass absorption coefficients of various media.

TABLE XXVII

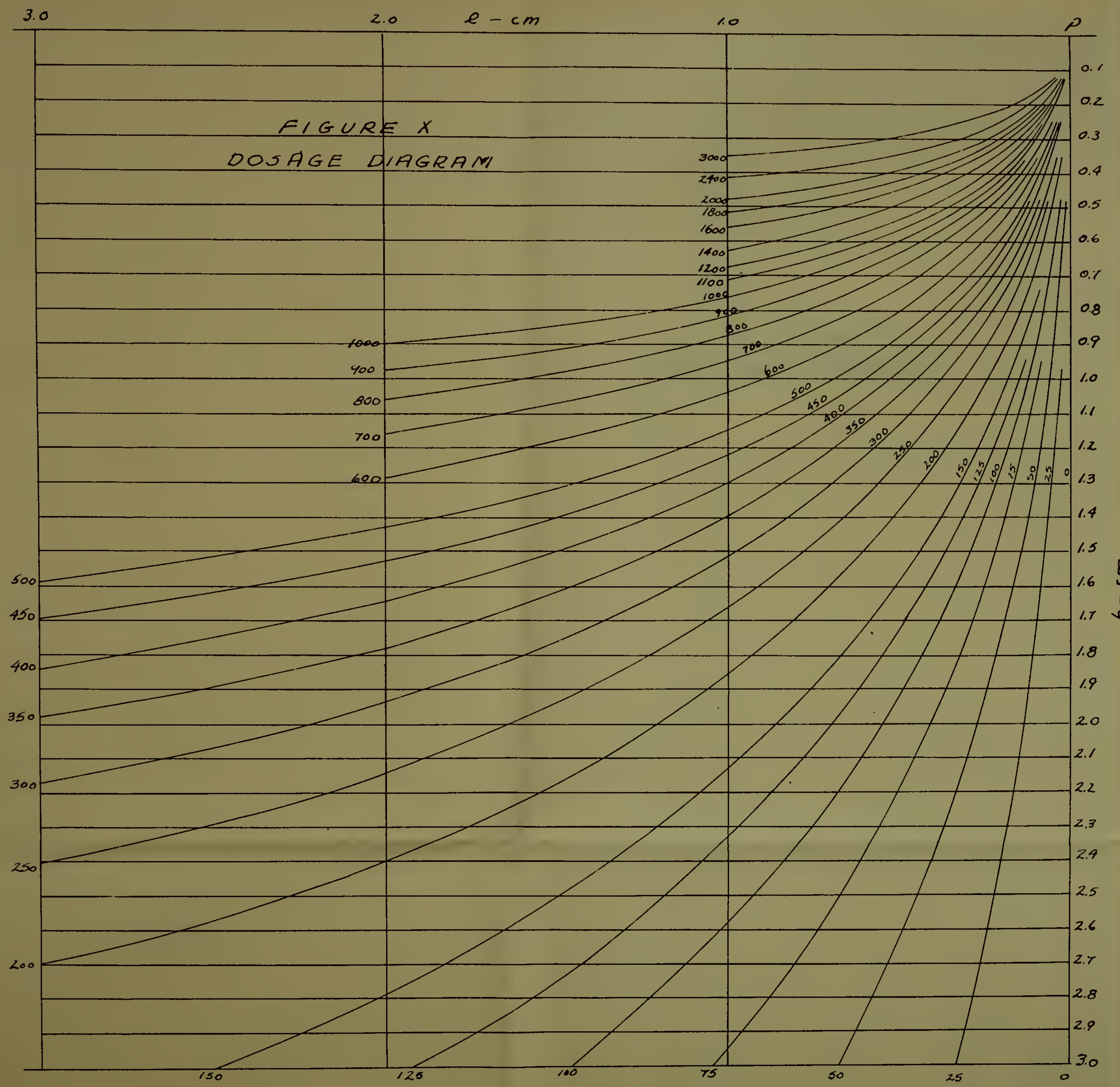
CALCULATED DOSAGE VALUES, 6 MIL WIRE

The tabular value is the angle ϕ in degrees necessary to give the stated lifetime dose in roentgens at point P in case I with points off the axis. h is given in centimeters. These values apply to t = 0.006" = 0.01524 cm and a gold shield of 0.020 centimeter thick.

r / h	0.125	0.250	0.375	0.500	0.750	1	1.250	1.500
25	- -	- -	- -	- -	1.24	1.71	2.19	2.71
50	- -	- -	1.19	1.61	2.48	3.42	4.38	5.41
75	- -	- -	- -	- -	3.72	5.13	6.58	8.12
100	0.77	1.57	2.39	3.22	4.96	6.82	8.78	10.84
125	- -	- -	- -	- -	6.21	8.54	10.98	13.52
150	- -	- -	3.58	4.83	7.46	10.25	13.18	16.29
200	1.54	3.15	4.78	6.45	9.95	13.69	17.60	21.79
250	- -	- -	5.98	8.07	12.45	17.13	22.07	27.35
300	2.30	4.72	7.17	9.71	14.95	20.62	26.56	33.05
350	- -	- -	8.38	11.33	17.46	24.09	31.11	38.83
400	3.07	6.29	9.57	12.96	20.00	27.60	35.73	44.76
450	- -	- -	10.76	14.58	22.52	31.13	40.47	51.02
500	3.85	7.86	11.96	16.20	25.05	34.64	45.29	57.60
600	4.62	9.42	14.35	19.45	30.15	41.90	55.42	74.07
700	5.39	10.99	16.75	22.71	35.31	49.46	67.03	- -
800	6.16	12.57	19.16	25.99	40.58	57.46	- -	- -
900	6.94	14.15	21.57	29.31	45.92	66.22	- -	
1000	7.71	15.72	23.99	32.30	51.45	77.76	- -	
1100	- -	- -	26.43	35.97	57.20	- -		
1200	9.26	18.89	28.95	39.36	63.27	- -		
1300	- -	- -	31.32	42.76	70.00	- -		
1400	10.81	22.06	33.79	46.21	78.59	- -		
1500	- -	- -	36.26	49.72	- -			
1600	12.36	25.25	38.75	53.28	- -			
1700	- -	- -	41.25	56.95	- -			
1800	13.92	28.45	43.78	60.73	- -			
1900	- -	- -	46.32	64.68	- -			
2000	15.48	31.65	48.91	68.86	- -			
2100	- -	- -	51.51	73.50	- -			
2200	17.08	34.89	54.17	79.12	- -			
2400	18.59	38.13	59.23	- -				
2600	20.15	41.41	65.00	- -				
2800	21.71	44.72	71.24	- -				
3000	23.27	48.07	78.86	- -				
3100	- -	- -	85.64	- -				

h / v	1.750	2	2.250	2.500	3
25	3.24	3.81	4.41	5.05	6.41
50	6.50	7.63	8.83	10.10	12.85
75	9.74	11.47	13.29	15.18	19.37
100	13.00	15.32	17.76	20.33	26.02
125	16.29	19.19	22.28	25.55	32.82
150	19.58	23.11	26.86	30.86	40.00
200	26.23	31.12	36.26	42.05	56.07
250	33.04	39.33	46.21	54.20	- -
300	40.03	48.00	57.27	70.43	- -
350	47.34	57.52	71.70	- -	
400	55.15	69.14	- -		
450	63.95	- -			
500	75.80	- -			

h / v	0.125	0.250
3500	27.20	56.66
4000	31.14	65.84
4500	35.11	76.52
5000	39.11	- -
5500	43.15	- -
6000	47.27	- -
6500	51.36	- -
7000	55.59	- -
8000	64.40	- -
9000	74.27	- -



TO USE DIAGRAM

1. Locate source replica at selected h
2. Take dosage readings at each end
3. Difference gives roentgens at ρ for a lifetime implant

DOSAGE DIAGRAM

r DOSE for LIFETIME IMPLANT of Au^{198} SOURCES

WIRE SIZES		TUBING SIZE
0.007"	0.005"	OD - 0.070 cm
0.006"	0.004"	ID - 0.030 cm

SCALE: 1 CM = 8 CM

TABLE XXVIII

CALCULATED DOSAGE VALUES, 5 MIL WIRE, ANGLE IN DEGREES

The tabulated value is the angle ϕ in degrees necessary to give the stated lifetime dose in roentgens at point P in case I for points off the axis. h is given in centimeters. These values apply to 5 mil wire and a 0.020 cm gold shield thickness.

r \ h	0.125	0.250	0.375	0.500	0.750	1	1.250	1.500
25	- -	- -	- -	- -	- -	1.71	2.19	2.71
50	- -	- -	- -	1.61	2.49	3.42	4.38	5.41
75	- -	- -	- -	- -	- -	5.13	6.58	8.13
100	- -	- -	- -	3.22	4.98	6.84	8.78	10.84
125	- -	- -	- -	- -	- -	8.55	10.98	13.56
150	- -	- -	- -	4.83	7.48	10.27	13.18	16.29
200	1.55	3.14	4.77	6.46	9.97	13.70	17.61	21.79
250	1.94	3.93	5.98	8.07	12.47	17.15	22.06	27.35
300	2.32	4.71	7.18	9.68	14.97	20.60	26.56	33.00
350	2.71	5.50	8.37	11.30	17.48	24.09	31.10	38.77
400	3.10	6.29	9.57	12.92	20.00	27.59	35.72	44.70
450	3.48	7.08	10.77	14.55	22.52	31.11	40.42	50.88
500	3.87	7.86	11.96	16.17	25.06	34.68	45.21	57.53
600	4.65	9.43	14.38	19.43	30.18	41.93	55.30	73.92
700	5.42	11.01	16.78	22.81	35.31	49.48	66.79	- -
800	6.19	12.59	19.18	25.99	40.54	57.43	- -	
900	6.97	14.16	21.59	29.29	45.89	66.17	- -	
1000	7.75	15.74	24.01	32.61	51.39	77.73	- -	
1100	8.52	17.32	26.43	35.95	57.11	- -		
1200	9.30	18.91	28.88	39.52	63.16	- -		
1400	10.84	22.08	33.77	46.16	77.77	- -		
1600	12.40	25.25	38.73	53.24	- -			
1800	13.95	28.45	43.74	60.67	- -			
2000	15.50	31.65	48.83	68.74	- -			
2200	17.06	34.89	54.09	78.82	- -			
2400	18.62	38.14	59.53	- -				
2600	20.18	41.41	65.22	- -				
2800	21.74	44.72	71.39	- -				
3000	23.31	48.06	78.89	- -				
3500	27.23	56.62	- -					
4000	31.17	65.72	- -					
4500	35.13	76.21	- -					

TABLE XXVIII - Cont'd.

r \ h	1.750	2	2.250	2.500	3
25	3.25	3.82	4.42	5.05	6.39
50	6.49	7.63	8.83	10.10	12.82
75	9.74	11.47	13.29	15.18	19.32
100	13.00	15.32	17.77	20.33	25.91
125	16.29	19.21	22.29	25.55	32.73
150	19.58	23.11	26.87	30.87	39.82
200	26.23	31.06	36.28	42.00	55.78
250	33.03	39.29	46.24	54.25	- -
300	40.00	47.99	57.31	70.10	- -
350	47.32	57.54	- -		
400	55.07	69.04	- -		
450	63.83	- -			
500	75.43	- -			

TABLE XXIX

CALCULATED DOSAGE VALUES, 5 MIL WIRE
DISTANCE IN CENTIMETERS

The tabulated value is the distance l in centimeters corresponding to the angle ϕ in the preceding table for a scale expansion of eight. h is given in centimeters and $l = 8h \tan\phi$.

r \ h	0.125	0.250	0.375	0.500	0.750	1	1.250	1.500
25	- -	- -	- -	- -	- -	0.24	0.38	0.58
50	- -	- -	- -	0.11	0.26	0.48	0.76	1.13
75	- -	- -	- -	- -	- -	0.71	1.15	1.71
100	- -	- -	- -	0.22	0.52	0.96	1.54	2.30
125	- -	- -	- -	- -	- -	1.20	1.94	2.89
150	- -	- -	- -	0.34	0.79	1.45	2.34	3.51
200	- -	0.11	0.25	0.45	1.05	1.95	3.17	4.79
250	- -	0.14	0.31	0.57	1.32	2.47	4.05	6.21
300	- -	0.16	0.38	0.68	1.60	3.01	5.00	7.80
350	- -	0.19	0.44	0.80	1.89	3.57	6.03	9.73
400	- -	0.22	0.50	0.92	2.18	4.18	7.19	11.90
450	- -	0.25	0.57	1.04	2.49	4.82	8.51	14.80
500	0.07	0.28	0.64	1.16	2.81	5.53	10.10	18.90
600	0.08	0.33	0.77	1.41	3.49	7.18	14.40	41.60
700	0.09	0.39	0.90	1.68	4.25	9.35	23.30	- -
800	0.11	0.45	1.04	1.95	5.14	12.50	- -	
900	0.12	0.50	1.19	2.24	6.20	18.10	- -	
1000	0.14	0.56	1.34	2.56	7.52	36.80	- -	
1100	0.15	0.62	1.49	2.90	9.28	- -		
1200	0.16	0.68	1.66	3.27	11.90	- -		
1400	0.19	0.81	2.01	4.16	27.70	- -		
1600	0.22	0.94	2.41	5.36	- -			
1800	0.25	1.08	2.87	7.12	- -			
2000	0.28	1.23	3.43	10.30	- -			
2200	0.31	1.40	4.14	20.20	- -			
2400	0.34	1.57	5.10	- -				
2600	0.37	1.76	6.50	- -				
2800	0.40	1.98	8.92	- -				
3000	0.43	2.23	15.30	- -				
3500	0.52	3.03	- -					
4000	0.60	4.44	- -					
4500	0.70	8.15	- -					

TABLE XXIX - Cont'd.

r \ h	1.750	2	2.250	2.500	3
25	0.79	1.07	1.39	1.76	2.69
50	1.59	2.16	2.79	3.56	5.46
75	2.40	3.25	4.26	5.42	8.40
100	3.23	4.38	5.76	7.40	11.60
125	4.09	5.57	7.37	9.46	15.40
150	4.98	6.81	9.11	12.00	20.00
200	6.89	9.62	13.20	18.00	35.30
250	9.10	13.10	18.80	27.80	- -
300	11.80	17.80	28.00	54.20	- -
350	15.20	25.20	- -		
400	20.10	41.80	- -		
450	28.50	- -			
500	53.90	- -			

These tabulated values are easier to plot than those in Table XXVIII since a grid system is used instead of polar coordinate paper.

PATERSON PARKER SYSTEM

FIGURE XI

PHYSICAL ARRANGEMENT FOR DOSAGE CALCULATIONS

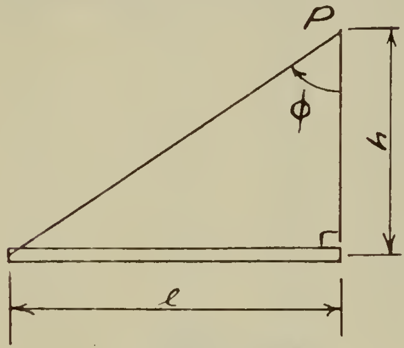


TABLE XXX

CALCULATED DOSAGE VALUES, 6 MIL WIRE

The tabulated value is the lifetime dose in roentgens at point P in Figure XI for geometry as given and a seed activity of 1 mrhm/cm. The gold tubing thickness is 0.020 centimeters.

Value of l in cm

h cm	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
0.50	1365	1867	2059	2145	2191	2218	2231	2241
0.707	746	1129	1305	1396	1447	1475	1495	1509
1.118	309	527	659	739	788	821	841	857
1.58	156	276	368	427	470	499	521	535
2.06	86	161	222	268	297	322	346	360
2.55	54	102	144	178	205	226	242	255
3.04	36	69	99	125	146	163	176	187
3.53	25	49	71	90	105	119	132	143
4.03	18	36	52	67	80	91	101	109
4.53	13	27	39	51	61	70	78	85
5.03	11	21	30	39	48	55	62	68
5.53	8	16	24	31	38	44	50	55
6.02	7	13	19	25	30	35	40	44
6.52	6	11	16	20	25	29	33	37
7.02	4	9	13	17	21	24	27	30

TABLE XXX - Cont'd

Value of l in cm

h cm	4.5	5.0	5.5	6.0	6.5	7.0
0.50	2249	2254	2259	2262	2263	2263
0.707	1516	1521	1526	1529	1532	1534
1.118	867	874	880	886	889	892
1.58	547	554	561	566	569	572
2.06	371	379	386	391	394	397
2.55	265	273	279	284	288	292
3.04	196	203	209	214	218	221
3.53	150	157	162	167	170	173
4.03	115	121	126	130	133	136
4.53	91	96	100	104	107	109
5.03	73	77	81	84	87	89
5.53	59	63	66	69	71	73
6.02	48	51	54	57	59	61
6.52	40	43	45	47	49	51
7.02	33	36	38	40	42	43

TABLE XXXI

SUMMARY OF PATERSON PARKER DOSAGE VALUES

The tabulated value is the seed activity in mrhm/cm/1000 r for the net areas given. It applies to 4, 5,6 or 7 mil wire in 0.020 centimeter gold tubing.

Tumor Size (cm)		Pattern Size (cm)		Treatment Time					
Net Size	Net Area	Gross Size	Gross Area	Life-time	10 days	9 days	8 days	7 days	%*
1x1	1	3x3	9	0.122	0.132	0.136	0.140	0.147	6.2
1x2	2	3x4	12	0.122	0.132	0.136	0.140	0.147	6.8
2x2	4	4x4	16	0.115	0.125	0.128	0.132	0.138	9.1
2x3	6	4x5	20	0.114	0.124	0.127	0.131	0.137	8.9
2x4	8	4x6	24	0.113	0.123	0.126	0.130	0.136	8.4
3x3	9	5x5	25	0.110	0.120	0.123	0.127	0.133	9.3
2x5	10	4x7	28	0.113	0.123	0.126	0.130	0.136	8.4
3x4	12	5x6	30	0.110	0.119	0.122	0.126	0.132	9.0
3x5	15	5x7	35	0.110	0.118	0.122	0.126	0.131	9.2
4x4	16	6x6	36	0.108	0.116	0.120	0.124	0.129	11.1
4x5	20	6x7	42	0.107	0.116	0.119	0.123	0.129	11.6
5x5	25	7x7	49	0.106	0.115	0.118	0.122	0.127	12.9

* These values give the greatest per cent variation

in the dosage for the net area specified.

As an example of its use, consider the following problem. There is a thin slab growth (<1 cm thick) on the forearm that has a maximum size of 3 cm x 3 cm. It is desired to treat the area with 5000 r with a 9 day irradiation time using an interstitial implant. An area 5 cm x 5 cm will be treated using 8 gold linear sources each 5 cm long. Six seeds will be placed through the area in parallel lines with a one centimeter spacing. The other seeds will be inserted across the ends of the six seeds so that the periphery is completely enclosed. The tabulated activity per 1000 r is 0.123 mrhm/cm. Therefore, the activity necessary for 5000 r in 9 days is 5 x 0.123 = 0.62 mrhm/cm at the time of implantation.

FIGURE XII

ARRANGEMENT OF GOLD-198 SOURCES

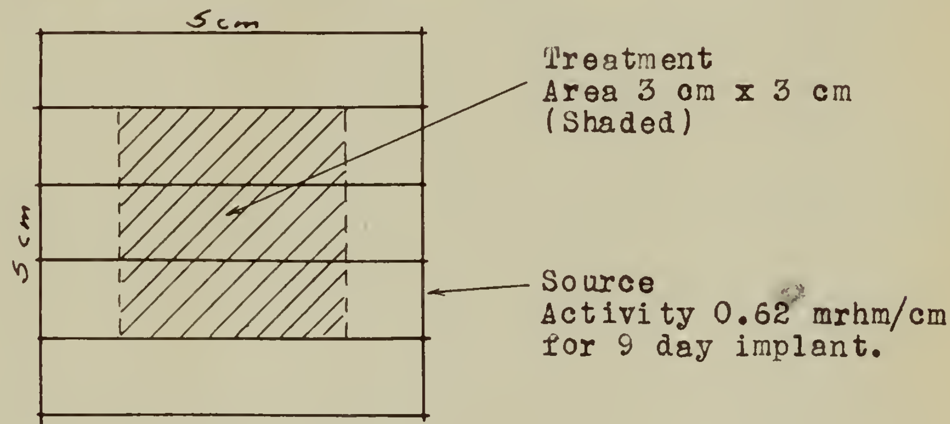
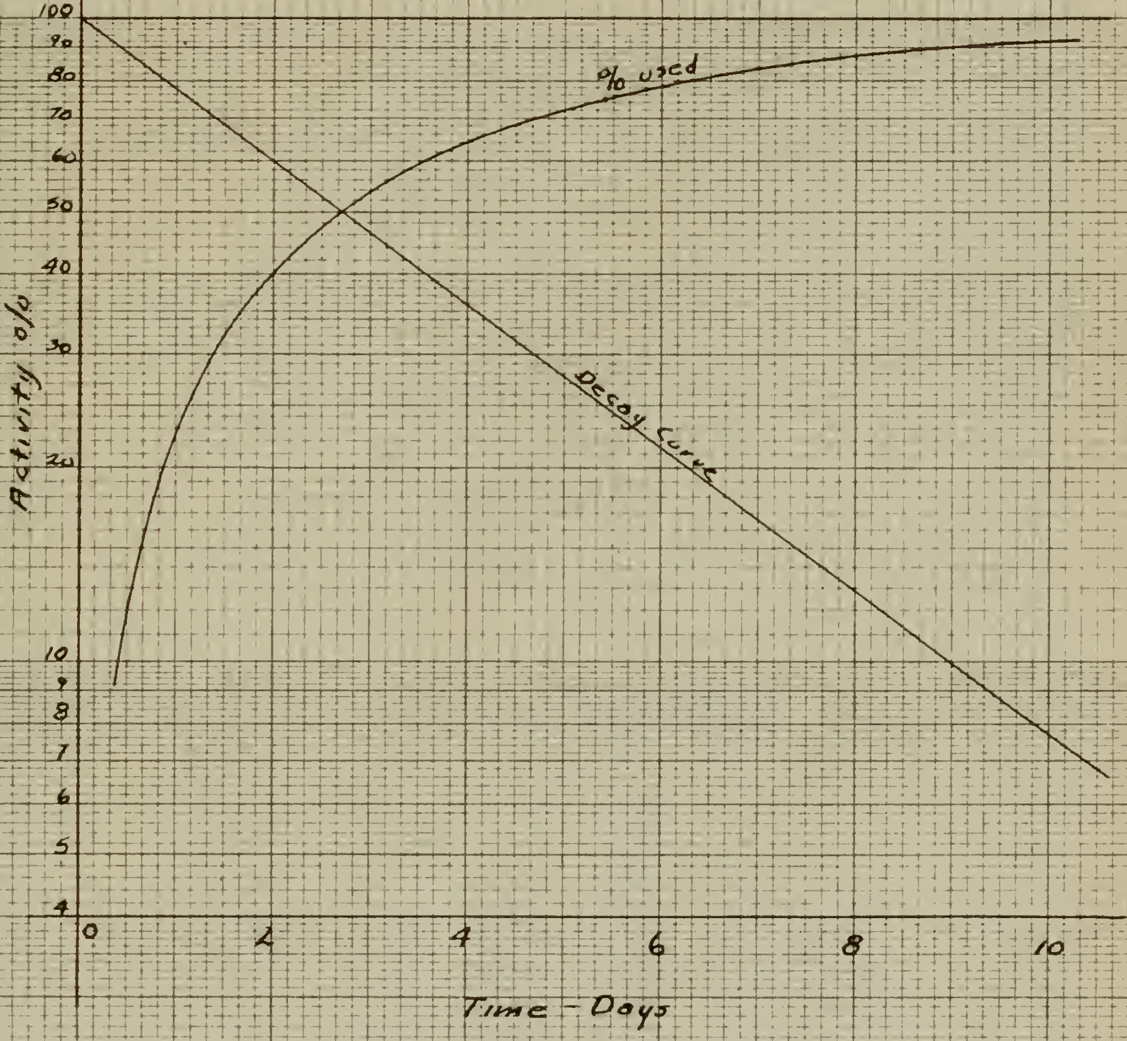


FIGURE XIII

DECAY CURVE
and
% ACTIVITY USED
for
Au-198



APPENDIX IV

ISODOSE LINES

CALCULATED ISODOSE LINES

A sketch of partial isodose lines about a 1 cm seed with 1 mrhm/cm activity is given on page 129. The seed was formed of 0.007" diameter wire enclosed in tubing with O.D. 0.032" and I.D. 0.015". Values from which these lines were plotted are given in the following table.

FIGURE XIV

PHYSICAL ARRANGEMENT FOR ISODOSE LINE CALCULATIONS

POINTS OFF THE AXIS

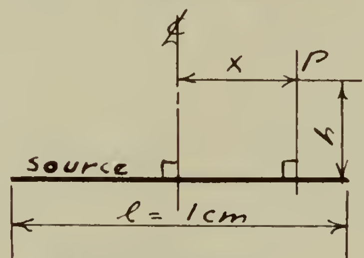


TABLE XXXII

CALCULATED ISODOSE LINE VALUES, 7 MIL WIRE

The tabular value is h in centimeters

Lifetime r at P	x in cm. 0	0.20	0.40	0.60	0.80
3000	0.49	0.47	0.42	- -	- -
2500	0.54	0.52	0.46	- -	- -
2000	0.61	0.59	0.53	0.44	- -
1500	0.73	0.70	0.64	0.52	- -
1200	0.83	0.81	0.76	0.62	0.48
1000	0.92	0.90	0.86	0.76	0.53
900	0.98	0.94	0.90	0.83	0.58
800	1.03	1.02	0.96	0.89	0.66
700	1.10	1.08	1.04	0.96	0.82
600	1.18	1.17	1.12	1.05	0.96
500	1.30	1.28	1.24	1.16	1.05
400	1.47	1.44	1.41	1.33	1.18

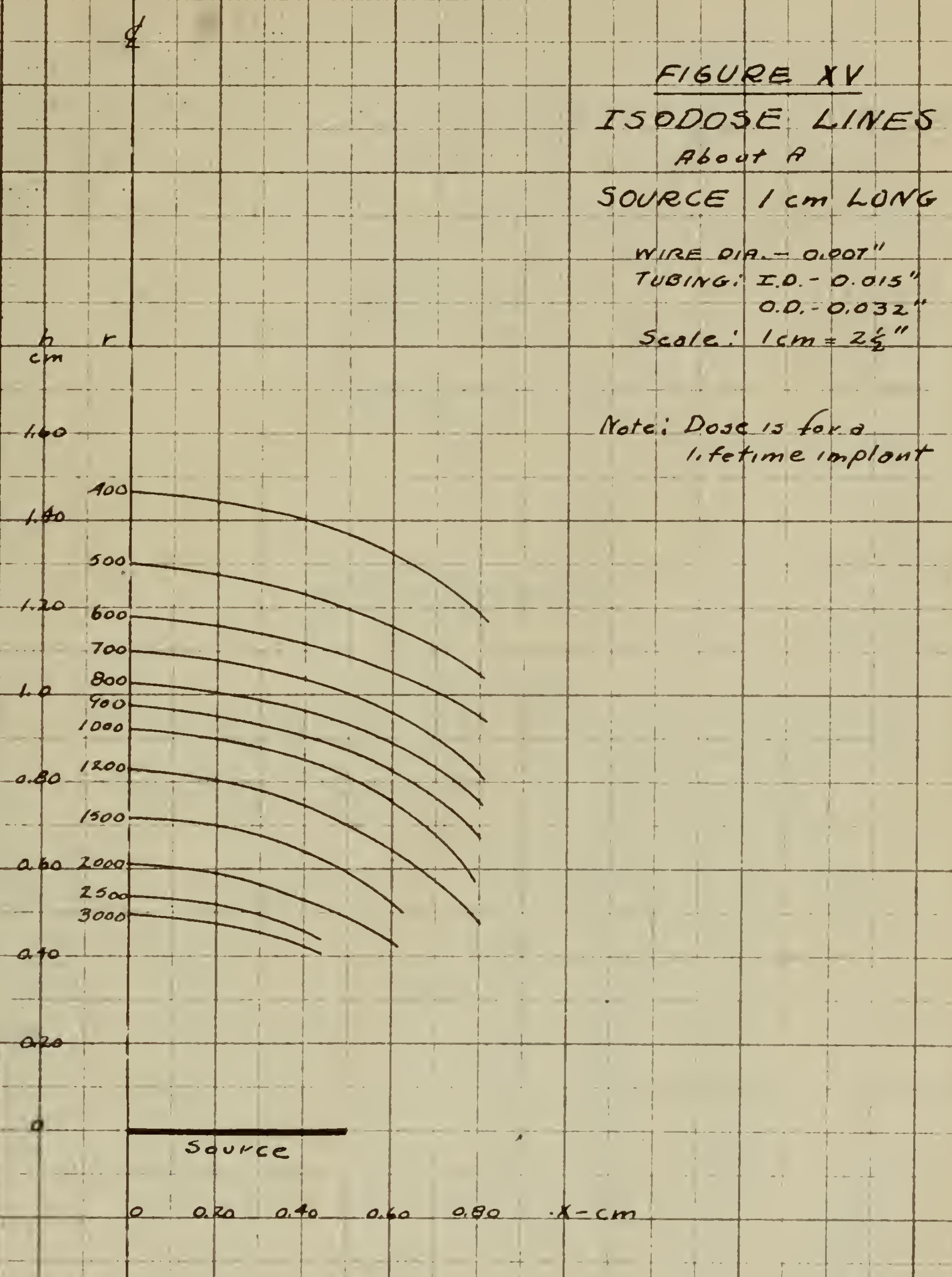


FIGURE XV
ISODOSE LINES
About A
SOURCE 1 cm LONG
WIRE DIA. - 0.007"
TUBING: I.D. - 0.015"
O.D. - 0.032"
Scale: 1cm = 2½"
Note: Dose is for a lifetime implant
h cm
r
1.60
1.40
1.20
1.0
0.80
0.60
0.40
0.20
0
400
500
600
700
800
900
1000
1200
1500
2000
2500
3000
Source
0
0.20
0.40
0.60
0.80
X-cm

CALCULATED ISODOSE LINES

A sketch of isodose lines about a source 1.5 cm long with 1 mrhm/cm activity is given on page 133. The seed was formed of 0.006" diameter wire enclosed in tubing with O.D. 0.070 cm and I.D. 0.030 cm. Values from which the lines were plotted are given in the tables:

FIGURE XVI

PHYSICAL ARRANGEMENT FOR ISODOSE LINE CALCULATIONS

POINTS OFF THE AXIS

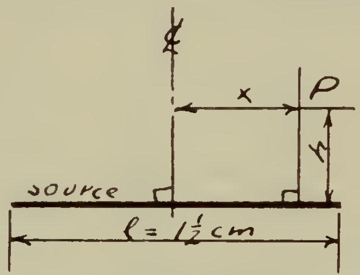


TABLE XXXIII

CALCULATED ISODOSE LINE VALUES, 6 MIL WIRE

The tabulated value is h in centimeters.

Lifetime r at P	x in cm. 0	0.25	0.50	0.75	0.875	1.00	1.25
4000	0.47	- -	0.36	0.28	0.13	- -	- -
3500	0.49	- -	0.41	0.32	0.18	- -	- -
3000	0.54	0.52	0.48	0.37	0.24	- -	- -
2500	0.61	0.59	0.54	0.43	0.30	- -	- -
2000	0.70	0.68	0.63	0.51	0.40	- -	- -
1500	0.82	0.80	0.74	0.64	0.55	0.40	- -
1200	0.94	0.91	0.85	0.74	0.66	0.56	- -
1000	1.03	1.01	0.95	0.85	0.78	0.69	- -
900	1.09	1.07	1.01	0.92	0.84	0.75	- -
800	1.16	1.14	1.09	0.99	0.92	0.82	0.24 0.48
700	1.24	1.22	1.17	1.07	1.00	0.91	0.16 0.64
600	1.34	1.32	1.28	1.18	1.12	1.04	0.12 0.78

TABLE XXXIII - Cont'd

Lifetime r at P	0	0.25	0.50	0.75	0.875	1.00	1.25
	x in cm.						
500	1.47	1.45	1.41	1.32	1.25	1.17	0.89
400	1.66	1.63	1.58	1.50	1.44	1.36	1.16
300	1.89	1.87	1.83	1.75	1.70	1.64	1.45
200	2.30	2.27	2.24	2.16	2.12	2.07	1.93

TABLE XXXIV

CALCULATED ISODOSE LINE VALUES, 6 MIL WIRE

The tabulated value is the distance x in centimeters.

Lifetime r at P	h in cm. 0.125	0.25	0.375	0.50
4000	0.88	0.79	- -	- -
3500	0.90	0.84	- -	- -
3000	0.92	0.88	- -	- -
2500	0.95	0.92	- -	- -
2000	0.99	0.98	0.94	- -
1500	1.05	1.06	1.02	0.94
1200	1.09	1.12	1.11	1.04
1000	1.13	1.18	1.18	1.12
900	1.16	1.21	1.22	1.18
800	1.18	1.25	1.26	1.23
700	1.21	1.29	1.31	1.29
600	1.26	1.34	1.38	1.38
500	1.32	1.42	1.48	1.48

FIGURE XVII

PHYSICAL ARRANGEMENT FOR ISODOSE LINE VALUES

POINTS ON THE AXIS

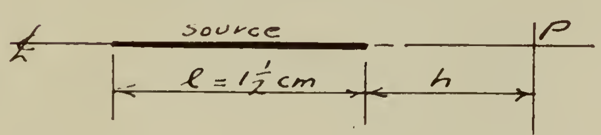


TABLE XXXV

CALCULATED ISODOSE LINE VALUES, 6 MIL WIRE

The tabulated value is the distance h in centimeters to point P, for each lifetime r at P, assuming a shield thickness of 0.01 cm at the end of the seed.

Lifetime r at P	h	Lifetime r at P	h	Lifetime r at P	h
3500	0,14	1500	0.26	800	0.40
3000	0.16	1200	0.30	700	0.42
2500	0.18	1000	0.34	600	0.46
2000	0.21	900	0.36		

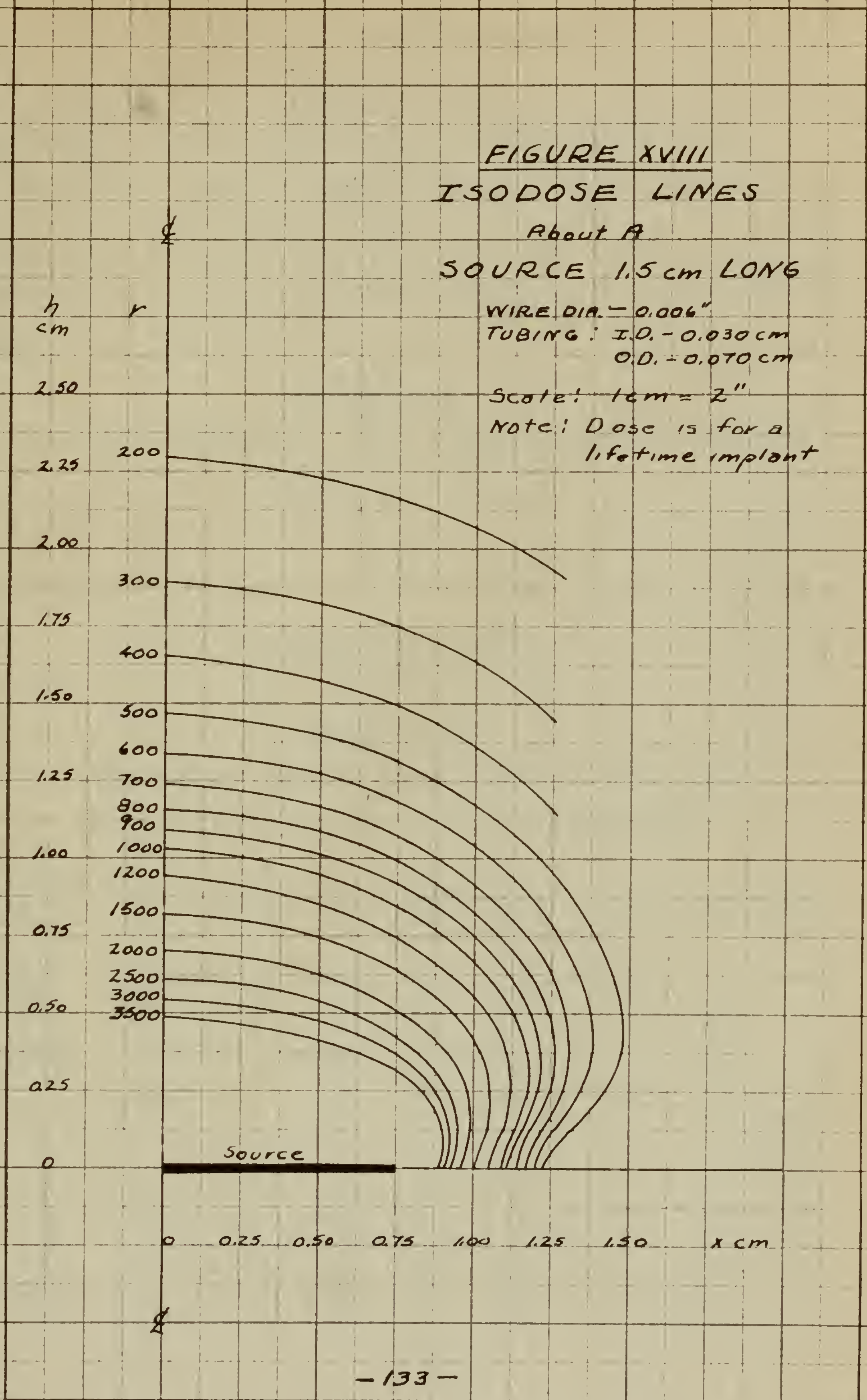


FIGURE XVIII

ISODOSE LINES

About A

SOURCE 1.5 cm LONG

WIRE DIA. – 0.006"
TUBING: I.D. – 0.030 cm
O.D. – 0.070 cm

Scale: 1 cm = 2"

Note: Dose is for a lifetime implant

CALCULATED ISODOSE LINES

A sketch of the isodose lines about a source 2.5 cm long with 1 mrhm/cm activity is given on page 136. The seed was formed of 0.006" diameter wire enclosed in tubing with O.D. 0.070 cm and I.D. 0.030 cm. Values from which these lines were plotted are given in the following tables:

FIGURE XIX

PHYSICAL ARRANGEMENT FOR ISODOSE LINE CALCULATIONS

POINTS OFF THE AXIS

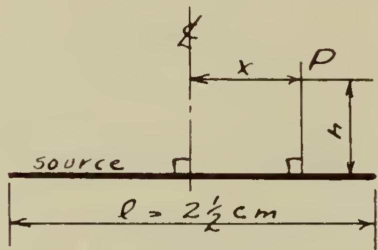


TABLE XXXVI

CALCULATED ISODOSE LINE VALUES, 6 MIL WIRE

The tabulated value is h in centimeters.

Lifetime r at P	x in cm. 0	0.25	0.50	0.75	1.00	1.25	1.50	1.75
3000	0.62	- -	- -	- -	0.50	0.37	- -	- -
2500	0.70	0.69	0.68	0.67	0.58	0.44	- -	- -
2000	0.81	0.80	0.78	0.74	0.67	0.54	0.22	- -
1500	0.98	0.96	0.93	0.88	0.82	0.68	0.45	- -
1200	1.12	1.11	1.08	1.02	0.95	0.82	0.62	- -
1000	1.24	1.23	1.20	1.15	1.05	0.94	0.74	- -
900	1.32	1.30	1.27	1.22	1.12	1.02	0.82	0.40
								0.27
800	1.41	1.40	1.36	1.30	1.20	1.10	0.92	0.59
700	1.52	1.50	1.48	1.40	1.30	1.21	1.04	0.76
600	1.64	1.64	1.60	1.53	1.44	1.34	1.18	0.93
500	1.80	1.78	1.76	1.70	1.62	1.51	1.36	1.14
400	2.02	2.00	1.98	1.91	1.84	1.73	1.58	1.38
300	2.32	2.30	2.28	2.24	2.16	2.06	1.93	- -
200	2.84	2.82	2.78	2.73	2.66	2.58	2.48	- -

CALCULATED ISODOSE LINES

TABLE XXXVII

CALCULATED ISODOSE LINE VALUES, 6 MIL WIRE

The tabulated value is x in centimeters.

Lifetime r at P	h in cm. 0.125	0.25	0.50
3000	1.42	1.38	- -
2500	1.45	1.43	1.16
2000	1.49	1.49	1.31
1500	1.55	1.57	1.45
1200	1.60	1.63	1.58
1000	1.64	1.69	1.67
900	1.67	1.74	1.72
800	1.70	1.79	1.78

FIGURE XX

PHYSICAL ARRANGEMENT FOR ISODOSE LINE VALUES

POINTS ON THE AXIS

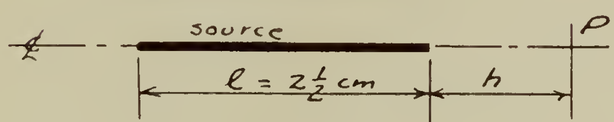


TABLE XXXVIII

CALCULATED ISODOSE LINE VALUES, 6 MIL WIRE

The tabulated value is the distance h in centimeters to point P, for each lifetime at P, assuming a shield thickness of 0.01 cm at the end of the seed.

Lifetime r at P	h	Lifetime r at P	h	Lifetime r at P	h
3500	0.15	1500	0.27	800	0.37
3000	0.16	1200	0.30	700	0.40
2500	0.19	1000	0.33	600	0.44
2000	0.22	900	0.35		

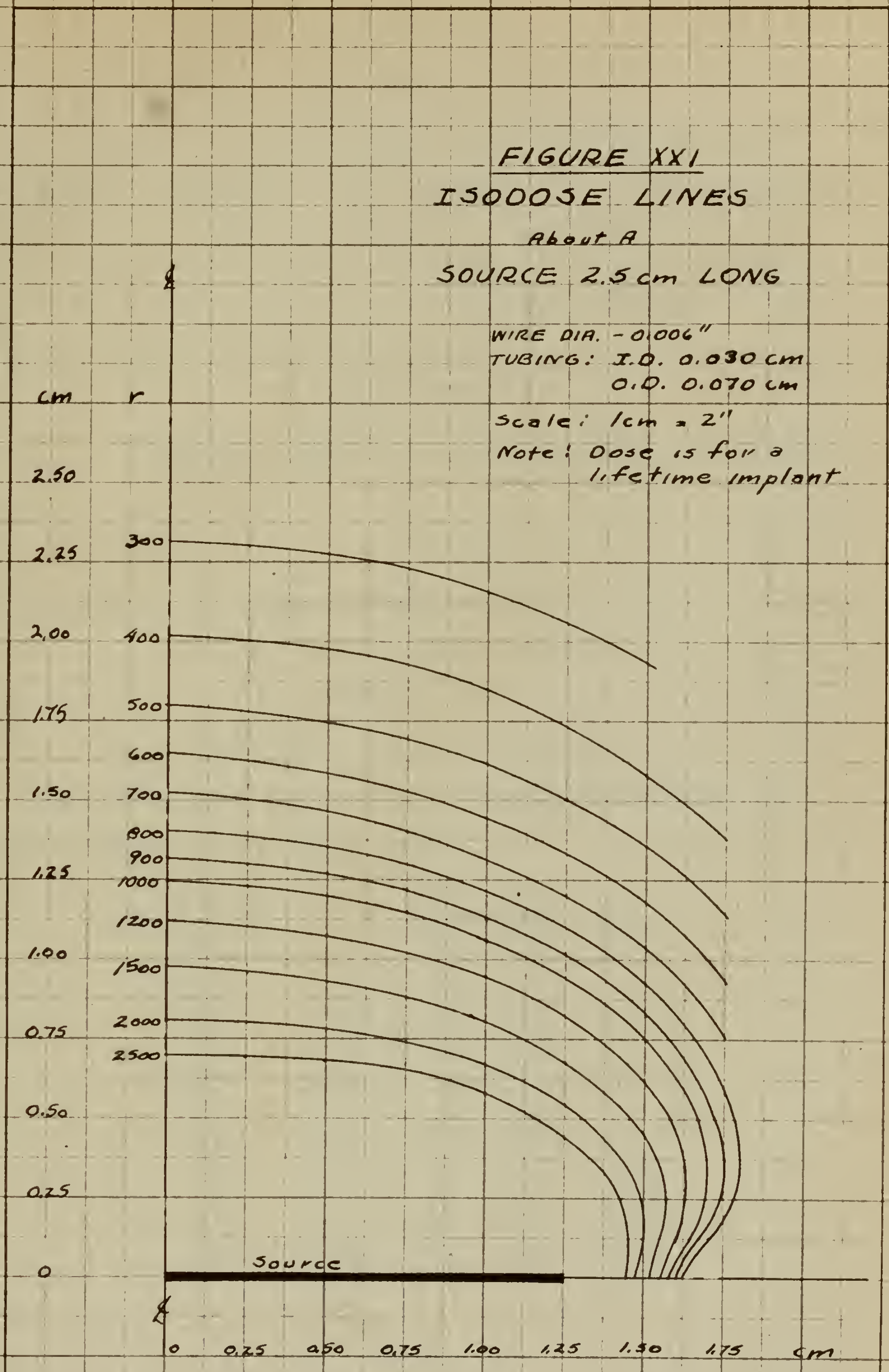


FIGURE XXI
ISODOSE LINES
About A
SOURCE 2.5 cm LONG
WIRE DIA. - 0.006"
TUBING: I.D. 0.030 cm
O.D. 0.070 cm
Scale: 1cm = 2"
Note: Dose is for a lifetime implant
cm
r
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0
300
400
500
600
700
800
900
1000
1200
1500
2000
2500
Source
0
0.25
0.50
0.75
1.00
1.25
1.50
1.75
cm

ISODOSE LINES BY

THE AUTORADIOGRAPH TECHNIQUE

One set of lines was determined using the autoradiograph technique. As a source, 7 mil wire enclosed in I.D. 0.030 cm, O.D. 0.070 cm gold tubing was used. The length of the source was 2.0 cm. A sketch of the isodose lines is given on page 139.

FIGURE XXII

PHYSICAL ARRANGEMENT FOR ISODOSE LINE DATA

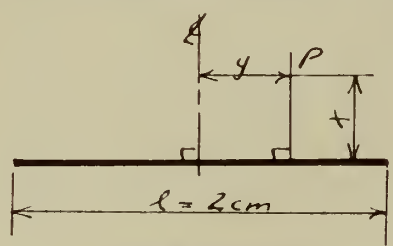


TABLE XXXIX

OBSERVED ISODOSE LINE DATA

The tabulated value is x in centimeters for the conditions given in Figure XXII.

Lifetime r at P	y in cm: 0	0.5	1.0	1.5
3000	0.57	0.46	0.27	- -
2500	0.67	0.60	0.39	- -
2000	0.77	0.72	0.50	- -
1500	0.93	0.87	0.66	- -
1200	1.06	0.99	0.78	- -
1000	1.16	1.08	0.88	- -
900	1.23	1.14	0.94	- -
800	1.31	1.22	1.02	0.37
700	1.40	1.29	1.08	0.58
600	1.52	1.38	1.20	0.75
500	1.65	1.50	1.32	0.90
400	1.83	1.64	1.47	1.05

TABLE XL

OBSERVED ISODOSE LINE DATA

The tabulated value is y in centimeters for the conditions given.

Lifetime	x in cm				
r at P	0	0.25	0.5	1.0	1.5
3000	1.24	1.04	0.42	- -	- -
2500	1.31	1.15	0.76	- -	- -
2000	1.35	1.24	1.00	- -	- -
1500	1.42	1.36	1.25	- -	- -
1200	1.45	1.43	1.35	0.35	- -
1000	1.48	1.48	1.41	0.70	- -
900	1.49	1.51	1.45	0.88	- -
800	1.51	1.54	1.48	1.03	- -
700	1.53	1.57	1.52	1.14	- -
600	1.57	1.62	1.58	1.28	0.08
500	1.62	1.69	1.65	1.41	0.52
400	1.68	1.76	1.74	1.53	0.88

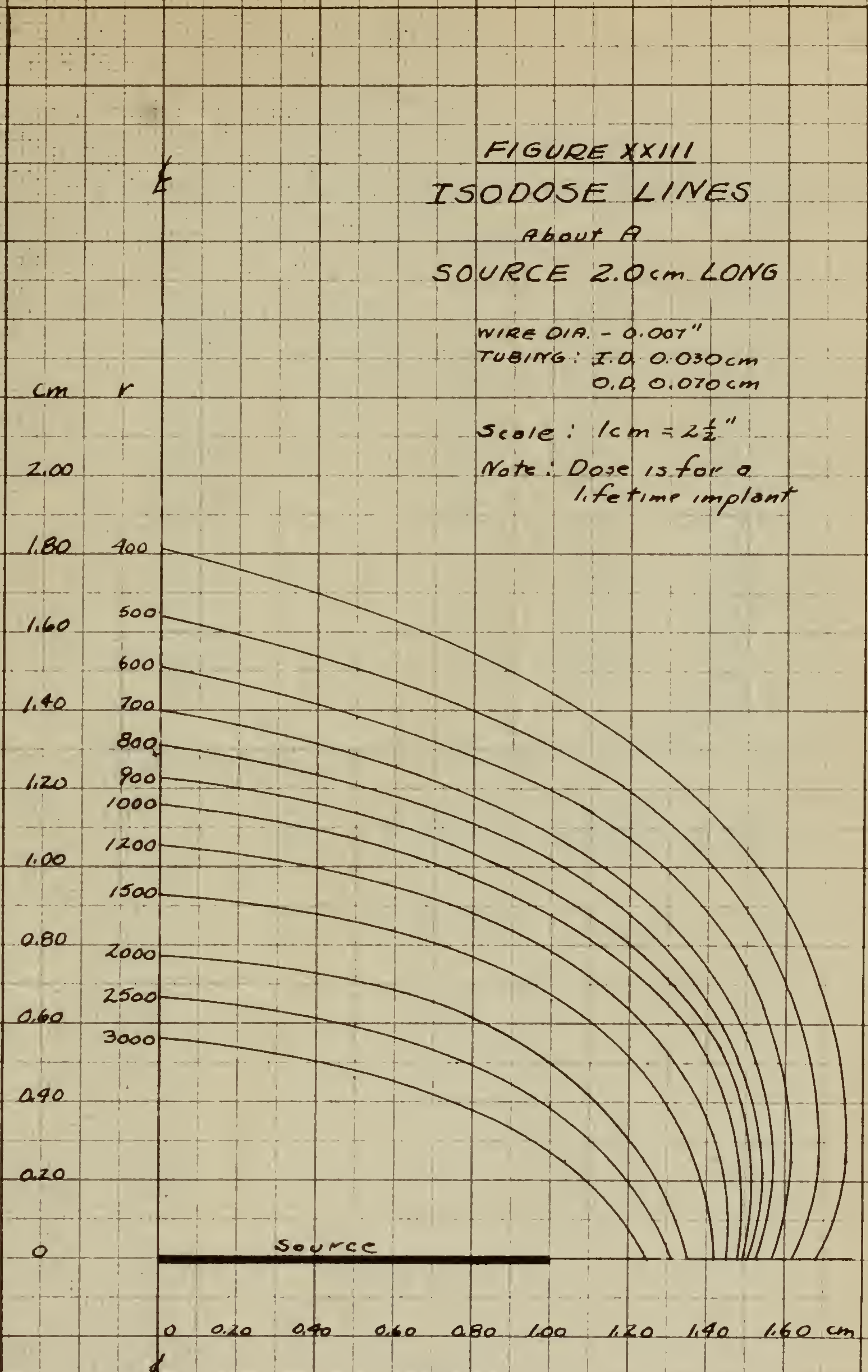


FIGURE XXIII
ISODOSE LINES
About A
SOURCE 2.0cm LONG
WIRE DIA. - 0.007"
TUBING: I.D. 0.030cm
O.D. 0.070cm
Scale: 1cm = 2½"
Note: Dose is for a lifetime implant
cm
r
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0
400
500
600
700
800
900
1000
1200
1500
2000
2500
3000
Source
0
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60 cm

APPENDIX V

TABLE XLI

RADON SEED DATA

The following tabulation gives the comparative data taken on twelve 1.46 mc radon seeds.

Seed	x Activity c/s	$\bar{x}$ Mean Activity	$x-\bar{x}$	% from mean	$(x-\bar{x})^2$
1	165.9	136.2	+29.7	+21.8	881
2	163.8		+27.6	+20.3	761
3	124.8		-11.4	- 8.4	130
4	167.1		+30.9	+22.7	955
5	136.3		+ 0.1	- -	-
6	118.1		-18.1	-13.3	328
7	126.4		- 9.8	- 7.2	96
8	127.8		- 8.4	- 6.2	70
9	121.5		-14.7	-10.8	216
10	125.7		-10.5	- 7.7	110
11	129.6		- 6.6	- 4.8	43
12	127.8		- 8.4	- 6.2	70
					3660

For small sample statistics Hoel (19) gives

$$\sigma = \sqrt{\frac{\sum_i (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{3660}{11}} = \sqrt{333}$$

σ = 18.2 c/s

APPENDIX VI

VIABILITY EXPERIMENTS

During the viability experiments, a variety of data were recorded. Included were the mouse and tumor strains, sex, type of experiment, date and time of excision, date and time of inoculation, number of takes, and comments on the technique among others. These data have been condensed below to include only the pertinent information.

In the tables, the two types of experiment will be listed as "Suspension" and "Lump". The "Suspension" experiments were those where the tumor after excision was immediately ground and placed in suspension in sterile saline. It was then incubated in the suspended form during the run. The "Lump" experiments were those in which the tumor was retained in sterile saline in lump form after excision, It was incubated in a lump and was ground just before injection into the healthy mice. Thus, both types of samples were kept in vitro for varying periods to determine the viability.

During the experiments, both male and female mice were used since they had been used in routine laboratory work without regard to sex and no difference in resistance had been noted. The sex was recorded but is not considered essential in the results.

TABLE XLII

VIABILITY DATA

Tumor: Lymphosarcoma

Mice : A Strain

Suspension			Lump		
Run	Hours	Takes	Run	Hours	Takes
1	0	Excised Tumor	1	0	Excised Tumor
1	½	6/6	1	0	6/6
1	1	4/6	1	2	0/6
1	1½	5/6	1	4	0/6
1	2	0/6	2	0	Excised Tumor
1	2½	0/6	2	0	3/6
1	3	0/6	2	12	0/6
1	4	0/6	2	16	0/6
1	5	0/6	3	0	Excised Tumor
1	6	0/6	3	0	0/6 *
1	21½	0/6	3	8	0/6
1	46½	0/6	4	0	Excised Tumor
1	69	0/6	4	0	6/6
2	0	Excised Tumor	4	8	0/6
2	0	5/6	5	0	Excised Tumor
2	8	0/6	5	0	1/6
2	12	0/6	5	12	0/6
2	16	0/6	5	16	0/6

Maximum Viability - 1 1/2 hours.

Maximum Viability - < 2 hours.

* Tumor was not viable since there were no takes at zero time.

TABLE XLIII

VIABILITY DATA

Tumor: Sarcoma 37

Mice : CFW Strain

Suspension

Run	Hours	Takes
1	0	Excised Tumor
1	2	4/6
1	4	3/6
1	8	0/6
1	12	0/6
1	16	0/6
1	22	0/6
2	0	Excised Tumor
2	0	6/6
2	2	3/6
2	4	1/6
2	8	0/6

Maximum Viability - 4 hours

Lump

Run	Hours	Takes
1	0	Excised Tumor
1	0	6/6
1	2	3/6
1	4	1/6
2	0	Excised Tumor
2	0	5/6
2	8	0/6

Maximum Viability - 4 hours

TABLE XLIV

VIABILITY DATA

Tumor: Adenocarcinoma, C3HBA

Mice : C3H Strain

Suspension

Run	Hours	Takes
1	0	Excised Tumor
1	0	6/6
1	2	6/6
1	4	6/6
1	8	6/6
1	12	0/6
1	16	0/6
2	0	Excised Tumor
2	0	6/6
2	12	0/6
2	16	2/6 *

Maximum Viability -
8 hours

Lump

Run	Hours	Takes
1	0	Excised Tumor
1	0	6/6
1	8	0/6
1	12	0/6
2	0	Excised Tumor
2	0	2/6
2	2	2/6
2	16	0/6
3	0	Excised Tumor
3	0	0/6
3	4	4/4
4	0	Excised Tumor
4	0	2/6
4	2	2/6
4	4	2/6

Maximum Viability -
4 hours

* These were believed to be bacterial infections due to faulty technique.

TABLE XLV

VIABILITY DATA

Tumor: Mammary Gland Carcinoma, 15091 a

Mice : ABC Strain

Suspension			Lump		
Run	Hours	Takes	Run	Hours	Takes
1	0	Excised Tumor	1	0	Excised Tumor
1	1	6/6	1	0	6/6
1	2	6/6	1	4	6/6
1	4	6/6	1	8	4/6
1	6	6/6	2	0	Excised Tumor
1	8	6/6	2	0	6/6
1	12	1/6	2	12	0/6
1	24	0/6	2	16	0/6
2	0	Excised Tumor	3	0	Excised Tumor
2	0	6/6	3	0	6/6
2	16	0/6	3	2	6/6

Maximum Viability - 12 hours

Maximum Viability - 8 hours

APPENDIX VII

ABBREVIATIONS

Abbreviations	Definition
Au-198, gold-198	These refer to the isotope $_{79}Au^{198}$.
Au-199	This refers to the isotope $_{79}Au^{199}$.
mrhm	This is an activity unit. It is the dose in milliroentgens per hour at one meter from the source.
cm	Centimeter.
mm	Millimeter.
mc	Millicurie.
c/s , c/t	Counts/second.
mg/cm^2	Milligrams per square centimeter.
psi	Pounds per square inch.
mg-hrs	Milligram hours.
Z	Atomic number of an isotope.
A	Mass number of an isotope or mouse strain.
mil	1/1000 inch.
R	Radius.
r	Roentgen -"The roentgen shall be the quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293 grams of air, produces, in air, ions carrying 1 esu of quantity of electricity of either sign." (44).
I.D.	Inner diameter.
O.D.	Outer diameter.

Abbreviations	Definition
mc^2	Energy equivalence of an electron.
Co-60	Cobalt isotope $_{27}Co^{60}$.
rd	One Rutherford or 10^6 disintegrations/second.

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